Stephen W. De Vries, P.E.

Total Cost of Transportation analysis of road and highway issues

May 2002

Submitted to:

Highway Division
of the
Iowa Department of Transportation
and
Iowa Highway Research Board

Project No. HR-388

FINAL REPORT

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Abstract

In the administration, planning, design, and maintenance of road systems, transportation professionals often need to choose between alternatives, justify decisions, evaluate tradeoffs, determine how much to spend, set priorities, assess how well the network meets traveler needs, and communicate the basis for their actions to others. A variety of technical guidelines, tools, and methods have been developed to help with these activities. Such work aids include design criteria guidelines, design exception analysis methods, needs studies, revenue allocation schemes, regional planning guides, designation of minimum standards, sufficiency ratings, management systems, point based systems to determine eligibility for paving, functional classification, and bridge ratings.

While such tools play valuable roles, they also manifest a number of deficiencies and are poorly integrated. Design guides tell what solutions MAY be used, they aren't oriented towards helping find which one SHOULD be used. Design exception methods help justify deviation from design guide requirements but omit consideration of important factors. Resource distribution is too often based on dividing up what's available rather than helping determine how much should be spent. Point systems serve well as procedural tools but are employed primarily to justify decisions that have already been made. In addition, the tools aren't very scalable: a system level method of analysis seldom works at the project level and vice versa.

In conjunction with the issues cited above, the operation and financing of the road and highway system is often the subject of criticisms that raise fundamental questions: What is the best way to determine how much money should be spent on a city or a county's road network? Is the size and quality of the rural road system appropriate? Is too much or too little money spent on road work? What parts of the system should be upgraded and in what sequence? Do truckers receive a hidden subsidy from other motorists? Do transportation professions evaluate road situations from too narrow of a perspective?

In considering the issues and questions the author concluded that it would be of value if one could identify and develop a new method that would overcome the shortcomings of existing methods, be scalable, be capable of being understood by the general public, and utilize a broad viewpoint. After trying out a number of concepts, it appeared that a good approach would be to view the road network as a sub-component of a much larger system that also includes vehicles, people, goods-in-transit, and all the ancillary items needed to make the system function. Highway investment decisions could then be made on the basis of how they affect the total cost of operating the total system.

A concept, named the "Total Cost of Transportation" method, was then developed and tested. The concept rests on four key principles: 1) that roads are but one sub-system of a much larger 'Road Based Transportation System', 2) that the size and activity level of the overall system are determined by market forces, 3) that the sum of everything expended, consumed, given up, or permanently reserved in building the system and generating the activity that results from the market forces represents the total cost of transportation, and 4) that the economic purpose of making road improvements is to minimize that total cost.

To test the practical value of the theory, a special database and spreadsheet model of Iowa's county road network was developed. This involved creating a physical model to represent the size, characteristics, activity levels, and the rates at which the activities take place, developing a companion economic cost model, then using the two in tandem to explore a variety of issues.

Ultimately, the theory and model proved capable of being used in full system, partial system, single segment, project, and general design guide levels of analysis. The method appeared to be capable of remedying many of the existing work method defects and to answer society's transportation questions from a new perspective.

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Total Cost of Transportation analysis of road and highway issues

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Chapter 1

INTRODUCTION

Total Cost of Transportation Analysis for roads and highways

1. Introduction

1a Concept overview

This report presents a proposed concept for analyzing road and highway issues. Called "**Total Cost of Transportation analysis"**, or **TCT**, it may be applied in deciding technical, administrative, and policy matters. Derived from a broad perspective of road based transportation, it applies economic cost analysis to assist road issue evaluation and decision making. The underlying concepts are easy to follow and can be implemented via personal computer based models.

Two 1993 road design and finance issues stimulated the quest for answers that resulted in this project. As the search progressed, additional topics and questions presented themselves and, in turn, suggested still others. This compounding effect led to a detailed review of road system decision making and inspired the concepts presented herein.

The first issue arose in Jackson County, Iowa, where the author was serving as county engineer. A group of residents submitted a petition for paving a road. This prompted the county supervisors to ask the engineer to determine what requirements would have to be met before paving could be done. A review of Farm-to-Market, (FM), road design aids indicated that the route's existing 1949-era cross-section, alignment, and profile fell well short of modern practice. So the petitioners were advised that re-design, right-of-way purchases, new culverts, a bridge replacement, and re-grading would have to precede any paving. Further, it was necessary to advise them that the process would take five to eight years to complete. They reacted with intense disappointment and complained that the upgrade requirements were excessive and unnecessary. "The road is OK as it is", they protested, "It doesn't need to be rebuilt – just finished."

Citizens often argue that recommended design criteria go beyond what's needed but usually approve of the roads that result from following that criteria. So, as County Engineer, the author defended the Farm-to-Market guides and insisted that they be followed. But his public resolve wasn't fully matched by personal conviction. Due to the high cost of reaching the FM design level, it would take at least six years and $1,600,000 dollars to meet the FM guidelines. In contrast, a narrower pavement could be placed on the existing grade in just two years for under $500,000 dollars. Since following the FM criteria would delay delivery of an all weather surface and consume $1.1 million that could otherwise be spent on other pressing needs, it was difficult to insist that lesser design options be excluded from consideration. Further, the west half of the same route had already been paved without being re-graded. It seemed to be providing safe, adequate service – so the petitioners assertion that their section should be done the same way was difficult to refute.

The situation brought forth several questions about road project design and planning:

a) How had the FM design guides been established and with what authority? What data, analysis and research backed them up?
b) Were there circumstances where a designer could or should use lower, (or higher), design values those set forth in the FM guides?
c) Would it be better to build a reduced standard design relatively soon or to endure years of delay in order to attain a higher level of service?
d) How could one justify the need for completely rebuilding the road when a “next door” example of reduced standard construction was apparently proving itself adequate in actual service?
e) How did safety objectives mesh and interact with other considerations?

Investigation revealed the FM design guides had been compiled by a joint committee of county engineers and Iowa DOT Office of Local; Systems staff. (Bergmann, 1994) These professionals had pooled their knowledge of, and experience in, transportation to recommend design values for a number of traffic levels. The resulting document presented the results of their efforts in a tabular format that made it easy to select design criteria by traffic level. The guide values had been established more by consensus than research and no documentation of factors considered had been recorded. So the guides weren’t able to assist comparing the pro's and con's of two different design levels' ability to serve a particular traffic load. For that, one needed to turn to other higher level references or authorities.

These findings prompted additional questions and concerns:

a) Did the design guide values reflect economic and technical necessity or did they represent the highest level of service that the committee thought counties could afford?

b) Were there any other methods available for selecting design requirements – perhaps through a more fundamental analysis?
c) Should road designers view the guides as desirable targets or absolute minimums?

While the author pondered these matters, the second issue arrived in the mail. A book, entitled Transportation and Iowa's Economic Future, was published by the University of Iowa's Public Policy Center. A copy was mailed out to every county engineer in Iowa. This analysis of statewide transportation issues presented the findings of a research team and their advisory group of transportation professionals. In one section, it asserted that Iowa's road use tax allocation formula transferred too much money from state highways to the county road system. The authors argued that this "cross-subsidy" should be reduced to make Iowa more economically competitive. (Forkenbrock, Foster, & Crum, 1993). Their analysis originated from comparing traffic volumes carried by each system. This triggered additional questions:

a) Would allocating highway dollars proportional to traffic volumes best serve society's needs?
b) What other methods for calculating funding allocations existed and what were their merits?
c) Were there ways to decide how much money to spend on road systems without having to compare statistics between systems or jurisdictions?
d) Could one devise alternate methods based on economic analysis?

(The Policy Center book suggested a possible approach to this last item, noting that, "An efficient allocation of RUTF resources would reduce transportation costs . . . the most.") (Forkenbrock, et al., 1993, p. 57)

A review of RUTF allocation literature revealed that highway officials hadn't yet found a fully satisfactory method for deciding road revenue distribution. *Needs studies* divided such funds according to ratios between factors computed from traffic data, road conditions, and minimum design standards – but suffered from a number of technical deficiencies. (Cable, 1993) *Road finance studies* recommended that the State emphasize high rate of return traffic capacity improvements. (De Leuw, Cather, 1989) An *Iowa DOT guidebook* on performing economic evaluation of highway projects suggested using the net present value of driver/shipper benefits less highway costs be used to decide priorities (Wilbur Smith Associates, 1993) – but didn't provide a clearly defined way to determine this. *Functional classification* schemes had been conceived to allocate money on the basis of the level of service provided (Iowa State Highway Commission, 1971) – but hadn't been used because, when enacted, they reallocated responsibility without adjusting funding to match. *Composite methods* computed technical need factors from system and traffic attributes for use in making proportional allocations (Forkenbrock and Schweitzer, 1996) – but didn't explicitly deal with economic considerations. More recently, the Iowa Department of Transportation had proposed primary highway funds be allocated in percentages – first to each system and then by investment category within each system. (Tice, 1998).

As the author worked to make sense of all the different approaches to fund allocation, a number of similarities became apparent:

a) The schemes typically apportioned funds on a "share-of-need" basis: splitting revenues in proportion to numeric factors generated from traffic, road, and level of service data.
b) Benefit determinations valued roads almost exclusively on ability to carry traffic and only minimally for providing access to land.
c) Many methods' outcomes were somewhat pre-ordained by pre-judgements contained in the way the issues were framed.
d) Most methods weren't scalable: they could be applied at the network level or at a project level – but not to both.
e) None appeared able to directly determine what level of service was appropriate for a road or road network.

Eventually, the author concluded that the Jackson County road petition issues and road use tax allocation issues raised in the Forkenbrock study were parallel manifestations of the more general question: "What is the economic purpose of building and operating roads?"

Existing references, methods, and procedures fell short of being able to answer that question in specific terms. Instead, they operated primarily from a deterministic technical perspective – giving answers without analysis or incorporating past determinations thereof without further review. They also seemed to place too much reliance on relative proportion distribution of resources, weren't readily scalable and were often predisposed towards certain outcomes by their internal setup. Last, it was difficult, in many cases, to follow how outputs resulted from inputs.

Another deficiency that the methods seemed to have in common was a limited perspective: they tended to implicitly view the roads and highways as being the "transportation system" and looked at traffic as an abstraction that operated upon and affected the system. In addition, the author noted that the use of such tools tended to lead transportation professionals into approaching issues with that same mindset. After thinking about how this affected things, he concluded that this "the roads are the system" approach might be causing people, including himself, to operate with an incomplete understanding of the total picture. So he began to search for an expanded definition of what the "road-based transportation system" consists of.

The situation appeared to demonstrate need for a tool based upon technical and economic fundamentals, with a broader perspective, greater scalability, and freedom from internal biases. The TCT concept resulted from seeking to answer those needs.

The TCT concept is based upon four premises developed during the course of this project:

1. That the road-based transportation system consists not just of roads and highways but also vehicles, drivers, passengers, terminals, service and support businesses, parking facilities, a legal-institutional framework, and all other things involved in the movement of goods and people.

2. At any point in time, two levels of market forces determine the amount of driving and shipping that takes place within the system – first by establishing maximum capacity and, second, by controlling home much of that capacity gets used.

3. That the total cost, to society, of transportation is the sum of everything consumed, given up, or permanently committed in the production of the transportation activity level resulting from the market forces.

4. That the economic purpose of improving roads is to minimize that total cost.

TCT appears to have potential to supplement or augment conventional decision analysis tools used in road and highway administration. It can assist studying all types of issues, is fairly easy to understand, and relatively simple to implement. The research project's goal was to develop and test the concept and evaluate its ability to supplement conventional practice.

This report retraces the sequence in which the Total Cost of Transportation concept arose, outlines the basic theory used, shows how it may be implemented via database and spreadsheet models on a personal computer, and evaluates it's overall potential.

Chapter 1: Introduction : explains how the project originated and summarizes what it set out to accomplish.
Chapter 2: Background: reviews, in more detail, the questions and issues that inspired the research – and shows how they lead to the goals of the research.
Chapter 3: Theory: presents the theory and core concepts of the TCT method.
Chapter 4: Modeling: explains how the concept may be implemented using a personal computer spreadsheet.
Chapter 5: Cost analysis: explores what cost components need to be incorporated into a TCT style analysis
Chapter 6: Specific example: illustrates setting up a system level model based upon Iowa’s county road network.
Chapter 7: Applications: demonstrates how the model may be used to analyze a variety of system, county, and segment level issues.
Chapter 8: Applications: tests using TCT to analyze single project situations.
Chapter 9: Conclusions: presents the report’s findings, compares them to existing methods, reexamines the original questions, and suggests future directions.

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Chapter 2

BACKGROUND

2 Background

As noted in the introduction, a pair of issues that arose in 1993 triggered this research effort. For the author, they brought years of thinking about a variety of transportation issues into focus and stimulated a search for a context in which they could be better understood..

Part 2a recaps the issues that inspired the TCT project, noting major questions raised.
Part 2b summarizes the Part 2a findings and tabulates major issues and needs.
Part 2c classifies the Part 2b's needs into categories and identifies attributes that any new method of analysis should possess.

2a Issues that inspired a search for answers

This Chapter profiles the various issues that wove together to stimulate the TCT research. It starts with the two issues noted in the introduction, then presents others that came up during the search for answers. No single item was more important than another. They all contributed equally to inspiring the project.

2a-1 "Iron Bridge Road"

In the Fall of 1992, a group of citizens petitioned for the paving of County Road E23Y in south central Jackson County, Iowa. This route extended from Iowa Hwy 62 near Andrew, ten miles southeasterly to Spragueville. A bridge over the Maquoketa River divided the corridor in half, and inspired its local name -- *Iron Bridge Road.* The eastern section was gravel surfaced, while the west five miles featured a thin asphalt pavement placed on a 6 inch thick stone base. The 2½ inch asphalt cement concrete mat covered the roadbed from shoulder to shoulder, 26 feet wide, providing just enough room to mark two 11 foot traffic lanes and two 2 foot shoulders. The petition asked that similar paving be placed on the 28-foot wide top of the east segment – which had been built in 1949. Traffic volumes averaged between 150 and 250 vehicles per day along the route. Accident rates were comparable to statewide averages.

The issue that arose with this road was whether the east half of the route should be brought into conformance with current Farm-to-Market road standards prior to paving or just capped with a stone base and asphalt mat, as per the petition. The FM guides indicated that the road needed to be extensively realigned, both vertically and horizontally, and have its shoulder-to- shoulder width increased to 38 feet. That would necessitate expending over $300,000 per mile and could not be financed in less than 6 years, (at 1993 funding levels). In contrast, the base and mat approach would need only $100,000 per mile and could be implemented in about two years.

Table 2-1 lists the FM design requirements that applied to the situation along with the road's 1949 design elements for comparison. The FM values shown are those recommended for a road with current year traffic under 400 vehicles per day, in hilly terrain. (Ia DOT, Inst. Memo 3.210, 1992)

Table 2-1 Comparison of E23Y roadway to FM design guide values

Design Element	FM Guidelines	E23Y status in 1993
1. Design speed	45 MPH	35 to 45 MPH
2. Stopping Sight Distance	400 feet min.	Less than 400 feet in many locations.
3. Max. Horiz. Curvature	9.5 degrees	15 degrees
4. Max. Grade	7.0 percent	10 percent
5. Min. Pavement width	22 feet	Room for 22 feet available
5a. Min. shoulder width	6 feet	Maximum of 3 feet possible
6. Req. Road Top width	34 feet	Existing top width of 28 ft.
7. Min. width – new bridge	30 feet	N/A
8. Min. width – existing bridge	24 feet	22 feet
9. Max. roadway foreslope steepness	3:1	3:1
10. Max driveway cross slope steepness	6:1	2:1
11. Min. roadside clear zone from toe-of-slope	10 feet	Obstructed by trees, poles, and culvert headwalls.

Under state law, (Chapter 670.07, Code of Iowa 1993), the FM design aids recommendations had to be used unless the county could justify using lower criteria by conducting *design exception studies,* (Ia DOT, Inst. Memo 3.218, 1992). Such studies compared the incremental cost of safety improvements with their potential to reduce accident losses. If the analysis supported the choice, a designer could employ lower design levels than listed in the design guides. Separately, a county road *paving points procedure* had to be performed to determine whether or not paving the route was appropriate. (Ia DOT, Budget and Program Inst., 1995).

The E23Y corridor met the requirements for paving. But a review of available methods showed that an engineer could use the design guides and exception analysis to make a case for almost any design level desired. If one wished to insist that the citizens accept a complete upgrade, it was easy to say, “There is no choice – the design guides require it.” On the other hand it was also possible, using the exception process, to justify significantly lower standards of design -- due to a lack of accidents along the corridor. It appeared, in essence, that the conventional tools could be manipulated to justify any arbitrary choice but were not be particularly useful for evaluating which, of several possible design levels, would be the best.

The situation presented the author with a dilemma. The acceptable safety record of the previously paved, west segment made it hard to argue that the full FM requirements had to be followed, but it seemed unprofessional to justify a reduced set of design requirements merely because available tools made it possible to do so. A scaled down design would leave E23Y less safe than could be achieved with a full FM design. But the money saved could be used to provide more safety somewhere else. In addition, any improvement to E23Y would draw traffic off other routes, changing their traffic volumes and safety as well. An analysis of such tradeoffs appeared warranted but was clearly beyond the scope of available methods.

Ultimately, Jackson County decided to redesign the route to meet the Farm-to-Market criteria. But concerns about the limitations of existing decision-making tools remained. Whenever an opportunity presented itself, the author continued looking for better methods. As this search progressed, it began to appear that the best solution would be a method of analysis based on economic fundamentals.

2a-2 Univ. of Iowa Public Policy Center book

The University of Iowa's Public Policy Center published a book entitled Transportation and Iowa's Economic Future in 1993. It examined roads and highways, inland waterways, agricultural transportation, freight transportation, and ended with a series of transportation policy recommendations. In the road and highway Chapter, it argued that too much road use tax, (RUT), revenue derived from primary highway traffic went to "cross-subsidize" county roads. The authors estimated that $92 million of the $207 million 1990 county RUT allocation came from primary road system traffic. (Forkenbrock, et. al., 1993, Table 4-3, p 57). They felt that, "While some cross-subsidization is possible without serious [state economic] efficiency problems, it is excessive to redistribute [so great an amount] from the vitally important primary road category", and recommended that the fund transfer be reduced as much as possible. (Forkenbrock, et. al., 1993).

Further reading revealed that it called for distributing road use taxes in direct proportion to the total travel taking place on each road network -- as represented by vehicle miles of travel, (VMT). Table 2-2, below, illustrates how VMT based fund allocation would change the flow of resources:

Table 2-2 : Comparison of 1993 RUTF distribution factors with factors Proportionate to total traffic (Forkenbrock, et al, 1993, Table 4-2, p 56)

Juris-diction	**1990 VMT: Forkenbrock Table 4-2**	**Actual 1993 RUTF distribution factors**	**Suggested traffic based distribution factors**	**Changes in funding that would result:**
Primary	14,064,000,000	47.5 %	61%	28% increase
Secondary	3,995,000,000	32.5 %	17%	48% decrease
Municipal	5,106,000,000	20.0 %	22%	10% increase

As shown in column three of Table 2-2, if total traffic were used to apportion funds, the State road program would gain nearly 30 percent while secondary roads lost half of their RUTF revenues. City allocations would not change significantly.

While increased primary road funding would definitely benefit inter-city travelers, would making such a change automatically produce a net, statewide gain? Absent an increase in total RUT revenue, boosting funding for one system would force another to decline. This could result in a self-reinforcing process where the gaining system became more attractive while driving on the other system became progressively more difficult. This would tend to skew the traffic volume ratios still more towards the favored network. Taken to the extreme, this effect would result in a rural road system that was 10% excellent and 90% inferior. If the quality of secondary roads were significantly reduced, farmers and agri-businesses would experience increased operating costs and increased transportation difficulties. It seemed that their losses would offset a significant amount of primary highway benefit. That, coupled with the potential for the process to become self reinforcing led the author to conclude that traffic volume ratios couldn't serve as the sole criteria for determining the allocation of highway funds.

But how could one objectively decide the matter? Project design aids weren't of use in system level analysis. Plus, a review of allocation methods, as noted in the introduction, found that most worked by comparing relative needs – not absolute need. Though useful for determining how to divide what *could* be spent, such methods were unable to indicate how much *should* be spent. To decide how much money ought to be expended on a road system, one needed a tool based on something more substantive than ratios between statistical measures. So the author began to investigate whether it would be possible to identify the optimal funding level for any single road type.

Forkenbrock's book suggested a possible basis for devising such a method, pointing out that, "The only way that transportation investments can contribute to economic development is by reducing the cost of moving people or goods", (Forkenbrock et. al, 1993, p 32). This suggested that it would be necessary to better understand how spending money on roads reduced such costs before performing an analysis. Types of cost savings identified in the book included reductions in accident costs, reduced travel times, decreased fuel consumption, lowered cost of industrial inputs, improved logistics, and reduced pollution.

2a-3 Design exception analysis

Road networks include facilities that range from modern to obsolete because minimum acceptable design levels have generally increased over time. As the standards evolve, the gradual obsolescence of previous improvements creates a potential liability for road agencies. At some point, a litigant could sue for damages on the basis that the agency had failed to keep all roads in conformance with current standards. This could create serious problems because there isn't enough funding available to keep all roads simultaneously upgraded -- and financial awards to plaintiffs would have the perverse effect of siphoning off the scarce resources and making it harder to keep things in good condition.

To deal with the dilemma described above, Iowa law provides that as long as a road was built to the minimum guidelines in use at the time of its construction, the agency in charge has immunity from lawsuits faulting the route's level of design. (Chapter 670.07, Code of Iowa, 1993). But it is often difficult to design a road to minimum standards and stay within all technical and financial constraints relevant to the situation. High land costs, archaeological finds, burial sites, cemeteries, utility conflicts, and rough terrain can make it impossible to create a design that absolutely meets all guidelines. To enable roads to be built in such circumstances, a secondary standard of care permits designers to deviate from design aid values if the cost of building to meet them exceeds the benefit to be gained from doing so. The procedure for making this determination is called *design exception analysis* and is outlined in Chapter 3.218 of Iowa's Instructional Memorandums for County Engineers. (1992).

In design exception analysis, the project engineer reviews a road's accident history, computes the accident frequency, and the average cost per incident. Accident reductions are then predicted, based on the type and magnitude of improvements to be made. The estimated benefits are divided by the incremental costs required to produce them and the result is called a benefit-cost, or B/C, ratio. If the ratio for upgrading from one level of design to another is less than 0.80, the upgrade probably isn't justified. But if the ratio exceeds 1.20, the higher standards ought to be implemented. Between 0.80 and 1.20, designers are advised to weigh additional factors before making a choice between options.

Table 2-3 illustrates the types of safety improvements considered in exception analysis and lists their relative ability to reduce accident costs.

Table 2-3: Accident reduction effectiveness of various design options. For rural roadway Chapters. (Ia DOT Inst. Memo 3.216, 1992)

No.	Design options	Reduction
1	Combination of horizontal and vertical realignment + improved super-elevation	45%
2	Vertical realignment alone	30%
3	Widening of pavement and shoulders	28%
4	Place ACC overlay on road to increase friction	27%
5	Horizontal realignment alone	25%
6	Widen pavement but not shoulder	22%
7	Widen shoulders and flatten foreslopes	15%
8	Groove PCC pavement for friction	14%
9	Widen shoulders or flatten foreslopes	8%
10	Add roadway lighting	6%
11	Relocate entrances and/or flatten their foreslopes + add new signing.	5%
12	Add edge line markings	4%

Design exception analysis provides a means by which designers can both accommodate site specific constraints and retain the liability protection afforded by state law. Without it, highways would be much costlier to build. However, the method of analysis could use improvement. The most significant shortcoming is that there is no clear indication what degree of improvement is required to attain the indicated cost reductions shown in the table. For example, although Item 7 in the table indicates a 22 per cent accident reduction potential for widening shoulders, it’s obvious that widening a shoulder by two feet cannot give the same benefit as widening it by six feet. Nor does the procedure account for changes in the mix of accident types as a road is improved, address non-safety related factors, or account for the time value of money.

Questions that arose from those deficiencies included: a) could a better, more technically and financially correct method be found, b) shouldn't the comparison of alternative designs also consider other variable user costs besides safety, and c) how would incorporating the time value of money into the analysis affect the outcomes?

2a-4 ISTEA planning mandates

When the ISTEA Federal Transportation act went into effect in 1992, significant, new planning requirements were imposed on Iowa's local road jurisdictions by the Iowa DOT as a condition of retaining eligibility for Federal aid. All agencies qualified to receive Federal aid were made to join regional planning affiliations, develop long range transportation plans, conduct special efforts to involve the general public, and list candidate projects in regional and state "Transportation Improvement Plans".

These new, ISTEA inspired procedures appeared to be predicated on the following premises:

a) That local governments in rural areas needed to conduct their roadwork decision making at a regional, as opposed to local, level.
b) That imposition of transportation planning methods would overcome local governments' "bias" towards sub-allocation of revenues. (Pittenger and Maze, 1996)
c) That more highway dollars should be spent for transit and inter-modal projects.
d) That public officials needed to be much more aggressive in soliciting citizen input regarding transportation issues.

In contrast to those perspectives, local officials felt that they were already providing good service despite having to work with inadequate funding. They noted that cities and counties often collaborated effectively in establishing route continuity across common boundaries, were receiving pressure from citizens for better roads – not better transit, and frequently experienced vigorous citizen input on a person to person basis.

The ISTEA mandate for increased citizen outreach seemed highly idealistic and to overlook some practical difficulties. While ISTEA's authors apparently envisioned that the general public would participate broadly, in all aspects of transportation planning (Tondl, 1994), citizens tended to focus exclusively on projects that affected them personally. Also, if care wasn't taken in how a participatory process was presented, the people involved came to believe that they were empowered to make the final decision -- setting the stage for them to become disappointed and cynical when reminded that this wasn't possible. (De Vries, 1978) Plus, citizens often refused to accept participatory process results, even when they had been involved from start to finish, if the outcome was contrary to their own interests. (De Vries, 1995)

The ISTEA mandates thus stimulated a lot of discussion among affected officials and brought the following questions into focus:

1. Could regional planning actually improve road system decision making or was it simply an artifice to try to force someone else's value system on local governments?
2. Were there ever any circumstances in Iowa where it made sense to divert road money to transit and inter-model projects?
3. Was there any way to obtain citizen input in the comparing of project alternatives without over-inflating their expectations?

2a-5 Searching for definition of minimum standard rural road

Iowa's county engineers have long sought to define a minimum standard road. The objective of this effort was to determine what minimum level of service ought to be provided in rural areas. (Schornhorst, 1994) It would have established the minimum traffic volume for which gravel surfacing was justified and defined a uniform, statewide level of service on gravel roads. It was planned that, after reaching an acceptable consensus on the matter, the county engineers would lobby for sufficient funding to enable providing it. But opinions as to what constitutes a minimum service level varied greatly from county to county, so no final decision ever developed.

One difficult unresolved issue was the question of inter-county equity. From one point of view, one could argue that all counties should be required to observe the same minimum service standard. If this were done, jurisdictions with greater resources wouldn't be tempted to "waste" money providing higher than necessary service levels on low volume routes. On the other hand, it would be hard insist that a county couldn't exercise local judgement and improve service if they had the means to do so.

After reviewing this issue, the author concluded that service level decisions could not be made without consideration of the overall economic benefit of each road to its daily users and to society as a whole. No methods existed for conducting that type of review, although it seemed that service levels ought to be linked to traffic volumes in some way.

Interest in the issue has waxed and waned a number of times. Currently, it's no longer a priority. Yet, it would be quite useful to have better guidance for making service level decisions.

2a-6 Iowa's Quadrennial Needs study

The Iowa Quadrennial Needs Study was developed in the 1960's as a tool for predicting highway finance needs within the state. (Cable, 1993) It was originally used for three purposes: to determine and communicate financial need to the general public and the legislature, to provide factors for allocating Road Use Taxes among the Counties, and to indicate how much money should be apportioned for park and institutional roads. Over time, the state and cities gradually ceased relying on the Study's results for decision making, so it ended up essentially as a revenue distribution aid for counties. (As a result of 2001 negotiations between the DOT and the counties, the study will be discontinued completely after a final run in 2002.)

The Needs Study simulates twenty years of road operation, repair, reconstruction, and upgrades to determine the total need for each type of route. First, all roads are classified according to their function: local access, collector, arterial, etc. Then design guides are established for each class and costs of operation, repair, improvement, and replacement are collected from past budget and project records. Starting from base records that include current traffic, traffic growth rates, current road condition, and road capacity data, the Needs Study analysis software simulates the passage of twenty years, summing the costs as it goes. The final totals represent the total amount of money that would be required to upgrade every eligible road segment to the minimum design level and physical condition appropriate to traffic levels anticipated. It is not intended to realistic model what will actually happen, since available funding will fall well short of the total need. Instead, its goal is to identify relative needs between jurisdictions. (Ia DOT, Needs Study Seminar, 1989)

Table 2-4 outlines the main sequence of the need study procedure. Each step contains detailed sub-processes, with structures analyzed separately from the roads. The study is re-run every four years.

Table 2-4 : Quadrennial Needs Study Simulation Process
(Ia DOT, QNS Seminar, 1990)

Step Numbers	Description of process stage	Process outputs
1 – 7	Estimate traffic, determine volume to capacity ratios, estimate operating speeds, identify critical elements of each road segment.	Initial traffic and service level determinations.
8 –12	Determine current design level of each segment and rate sufficiency. If work is needed, figure design year traffic and identify required improvements from design guides.	Updated records with data on proposed improvements.
13 –16	Simulate improvements, then apply traffic impacts and weathering to model changes in physical condition.	Projected system status after next year of weathering and traffic.
17 – 19	Determine traffic, V/C ratio, speeds, and critical elements for next simulation year.	Intermediate results and cost figures.
*	Repeat Steps 8 through 19 until twenty years time passage has been modeled.	
20	Calculate and total all costs	Needs totals by jurisdiction.

The Needs Study process was an unquestioned part of the inter-county Road Use Tax allocation process for over twenty years. However, confidence in the study's results began to deteriorate in the 1980's because of ever increasing variability. (Cable, 1993) Some Counties' allocation factors plummeted by thirty percent in one cycle while a peer's jumped by twenty five points – even though the relative need level and system conditions of their jurisdictions appeared nearly unchanged. More confusing, when the analysis was run again, four years later, the factors could move just as dramatically in opposite directions. These gyrations became so extreme that the county engineers began to wonder if the procedure was still valid.

A special research project was commissioned to investigate why the model was generating such highly variable outputs. It checked to see if input data were sound, reviewed core algorithm logic, and tested how the model reacted when input data was deliberately shifted both up and down. (Cable, 1993) In the end, no definite reasons for the problem were found. It could only be stated that a number of factors, acting in combination, appeared capable of causing large variations in output. But more research would be required to find a reliable way to stabilize the outputs.

Next, a group of engineers teamed with researcher Dave Forkenbrock, of the University of Iowa, to try to devise a new, supplemental method for calculating inter-county allocation factors. This work combined data about traffic levels, system size, terrain types, and ability to pay and produced a very sophisticated calculation process. (Forkenbrock and Schweitzer, 1996) Unfortunately, the new method produced factors that would have required larger inter-county adjustments than caused by the Needs Study shifts if placed in service. So, even after an elaborate “hold harmless” phase-in plan was developed, the proposed method failed to win approval.

In the course of all the analysis and re-evaluation, it became clear that the Needs Study contained some unintended flaws and biases. The logic used in the simulation tends to reward poor maintenance and to penalize taking good care of a system. (Cable, 1993) The input data for some parts of the state was recent while the data from other areas could be as much as ten years old -- possibly skewing the results accordingly. The process could additionally be faulted for assuming that all roads would be fully upgraded when needed – without regard to financial limitations, and for failing to apprehend and account for changes in traffic patterns as new links opened. Preconceptions about level of service requirements were built into the study via the chosen design guides and one couldn’t clearly trace how input data resulted in a particular outcome. The methodology was so complex that it could not easily be explained to the general public and could only be used for system level analysis.

Thus it seemed desirable to consider how the study methodology might be refined to eliminate or reduce areas of technical weakness. Ideally, a refined system would eliminate conceptual bias, model real world limitations, avoid favoring or penalizing past efforts, use methods that produced results consistent with inputs, be comprehensible to non-experts, and be capable of dealing with either an entire network or just a single project with equal validity.

2a-7 Comparing trucking with railroading

In 1994, the author learned that railroad companies were, for the first time in decades, earning higher rates of return on their assets than most long-haul trucking firms. Curious about this, he obtained annual reports from several trucking companies and railroad corporations. Upon review, it became apparent that the railroads' performance was doubly impressive because the rail firms had to count more assets against earnings than did the trucking companies. Rail assets included rolling stock and terminals plus rights-of-way, tracks, signals, and bridges. In contrast, the trucking firms, operating over public highways, did not have to include any of the capital investment value of the road system in their financial performance calculations. Essentially, they enjoyed a tremendous accounting advantage over the railroads, yet were not achieving equal economic performance. If the rail firms had been able to exclude the value of traveled way assets from their balance sheets, their profitability would have been more than doubled. Conversely, if the truckers had to include the asset value of the road system in their books they would have been losing money. Table 2-5 illustrates the situation:

Table 2-5: Comparison of financial performance of rail and truck transport – 1994 (All financial data is shown in $1,000,000's)

Company and Fiscal Year	Total Assets	Assets less ROW, track, and Structures	Net earnings	Return on total assets	Return on non-roadway assets
BN Railroad – 1993	$7,045	$2,436	$296	4.2%	12.2%
UP Railroad – 1994	$10,455	$4,158	$754	7.2%	18.1%
Roadway Services, Inc. –	$1,949	$1,949	$20	1.0%	1.0%

1994					
J. B. Hunt Transport – 1994	$994	$994	$40	4.0%	4.0%
Carolina Freight Corp. – 1994	$370	$370	$7	1.9%	1.9%

These observations lead to several conclusions about highway finance and fuel taxes. Since the capital cost of road and highway improvements isn't explicitly charged out, trucks are able to leave a significant cost factor out of their price and financial performance determinations – giving them a special advantage over their rail competitors. A fully objective comparison of truck-haul versus rail economies would require that part of the capital cost of the roadways be included in motor carrier expenses. But, if society were to require that road-users pay a rate of return on the capital invested in roads and highways, gas taxes would have to be considerably increased. Such an increase would, in turn, induce more use of railroads and possibly slow the growth of highway traffic. So, even though society has elected not to charge end users for the cost of capital invested in the road network, it appeared to the author that such costs should be considered when making road upgrade and system extension decisions.

2a-8 The popular concept of the self serving highway lobby

There is a popular conception that road agencies, engineers, trucking firms, road contractors, and materials suppliers constitute a lobby that promotes overbuilding the road system. It is often suspected that this group pushes highway spending more to justify its own existence and to earn profits than to serve real transportation needs. A typical accusation states, "The highway lobby would like to … [go] back to the days when virtually all the money could only be used for highway construction". (Pierce, 1997) The implication is that absent the "highway lobby's" self-serving influence, society would devote more resources to "better" things like public transit, rail travel, and inter-modal shipping.

Most highway agencies do spend every dollar they take in, a fact that, superficially, appears to confirm the apprehension that the lobby is out to serve itself. But it might also indicate that road resources fall short of needs. For example, a 1996 Iowa study of county road finance found that, "… historical expenditures … do not equal costs, nor do they reflect need. What a county spends … is more … a function of what it is able to spend", and, "what a county *actually* spends may or may not be what it *should* be spending." (Forkenbrock & Schweizter, 1996) While the study pertained strictly to counties, the issues addressed by the excerpt apply to all road agencies.

To determine if a jurisdiction spends more or less than it ought to, one must first determine the correct, or optimal, level of expenditure so that actual spending can be compared to it. Proportional allocation methods won't work for this because they divide revenues according to relative, not absolute, need. Nor can other conventional analysis methods assist this quest – because of the various deficiencies cited in Part 2a-6. To effectively determine how much money should be spent and overcome the perception that a self-promoting complex exists, a better method is needed. It should be based on economic analysis and be able to be understood and accepted by the general public.

While it does seem that the highway transportation is over-emphasized in the United States, is that really because of a special interest group? Or are there other factors that apply to the situation? A new method would help answer those questions and assist in separating reality from perception.

2a-9 "Paving roads from nowhere to no place"

Iowa's network of paved county roads periodically gets criticized for being overbuilt and lacking route continuity. These complaints come from a number of sources, such as interstate users and urban officials, but the most consistent and sustained critic has been the Des Moines Register, Iowa's premier newspaper. At least once per year their editorial staff charges that county supervisors and engineers have built too many paved roads "from nowhere to no place". (Yepsen, 1995) While seldom explicitly stated, this antagonism towards county roads derives from the belief that the monies spent paving and maintaining rural roadways would better serve public need if spent on state or city routes instead.
In pondering these periodic attacks, the author concluded that there ought to be a way to objectively present how much money should be invested in any type of road system. Ideally, it would be accomplished via a tool that allows critics to submit inputs and participate in developing the results. Partial ownership of the inputs might somewhat oblige them to accept the results, however they came out, and help tone down the sniping.

2a-10 Sufficiency Ratings and Management Systems

As roads and highways age, the quality of service they provide gradually declines and they eventually need repair or replacement. Simultaneously, traffic growth places increasing demands on the roadways, eventually outstripping the safe capacity thereof. So road agencies constantly face the challenge of selecting the best possible mix of repair and improvement projects to serve public needs. To do this, they've devised many different prioritization aids. One of the most common is the *sufficiency rating*: a numeric factor computed from road condition, desired service level, consequences of service interruption, and level of traffic. Engineers and planners use these factors, once computed, to guide project choices.

The use of sufficiency ratings and other, similar, measures subtly affects how people approach and analyze road issues. Such factors induce the mind to view roads abstractly, and invite a perspective where roads are seen as separate from the traffic that uses them. In that situation, when a person speaks of the *transportation system*, the image in their mind often consists only of pavements, bridges, signs, and culverts. The drivers and vehicles that operate upon the fixed base get viewed as an abstract attribute of the roadways, expressed as traffic counts. However, while the roads *are* a network of pathways, they do not produce transportation by themselves. Other entities – such as cars, trucks, drivers, gas stations, car dealers, tire plants, contractors, state troopers, and driver's license bureaus, are also required. So, the "roads are the system" perspective, may lead people to unintentionally overlook the "total" system. To remedy this, it might be appropriate to force oneself to explicitly view the *transportation system* as consisting of all the aforementioned components, not just the roads. Then transportation decisions would be made from a much larger and more encompassing understanding of how transportation works. An expanded methodology would be needed to facilitate such an expanded approach.

In the last couple of decades, road departments have moved beyond merely ranking projects with sufficiency ratings and developed processes called *management systems*. These tools measure current road conditions, predict future deterioration, and interactively test various management strategies to maximize each road's useful lifetime. Management systems concepts have been under development for many years, yet have proven difficult to implement. As computer power increases and the cost of reliable data acquisition drops, however, they will eventually become very valuable tools. Yet, as with the sufficiency ratings, these methods also operate from a “roads are the system” perspective.

Methods like sufficiency ratings and management systems provide valuable assistance in analyzing and prioritizing but they also constrain and limit the overall framework in which problems get defined. To obtain enhanced understanding of road transport issues, it would help to adopt an enlarged vision of what constitutes the *transportation system*.

2a-11 The transfer of jurisdiction stalemate

Iowa developed a state functional classification plan for its roads in 1971. (Iowa Highway Commission) The major objective of that initiative was to assure that each type of road agency, (state DOT, county road departments, and city public works departments), would handle the classes of roadway that best fit their capabilities. At that time, there were numerous instances where the DOT was maintaining gravel roads that ought to be under county jurisdiction and where county routes carried enough traffic to warrant primary highway status.

Had the functional classification plan succeeded, it could have rationalized Iowa’s road system and assured that each route was assigned to the level of government best able to deliver the appropriate level of service. In the long run, that would have provided Iowans with an improved operation and maintenance structure for their road network. This realignment was to be achieved by *transfer of jurisdiction*, a process in which the DOT would have given its low traffic roads to counties and accepted high volume county routes in return. But the process failed due to a simple flaw in how it was implemented: funding didn’t follow responsibility.

The law provided for the jurisdictions to exchange mileage but didn’t provide for adjusting revenue allocations to match. So counties that took over state routes faced the prospect of either raising their property tax rates to compensate or of diluting already strained budgets. Many found that arrangement objectionable and lobbied hard for relief. Ultimately, they prevailed and the legislature softened the law – making transfer of jurisdiction optional instead of mandatory. Since that time, except where special circumstances make it mutually beneficial, transfers of jurisdiction have ceased taking place.

This outcome, although pre-ordained by the omission of a funding adjustment mechanism, was unfortunate. Iowa's road system never got fully realigned and there are still many roads today assigned to the wrong level of government. This results in a somewhat mismatched service delivery system where the state under-maintains it's lowest level roads – even though counties would typically give such routes first priority. Simultaneously, counties cannot afford to deliver needed service levels on higher volume routes that ought to be state roads.

Iowa still needs to have its road network responsibilities realigned. But it won't happen voluntarily unless provision is made to shift financial resources along with the roads. One way to accomplish this would be to devise a method of determining an appropriate, annual, per mile funding rate for each individual road segment. If such data existed, it would be possible to re-compute any jurisdiction's funding to fit its new mileage. This would make it much more attractive to road agencies to work out exchanges and to stop resisting the transfers. No conventional processes are capable of determining segment by segment allocations. A new method would have to be synthesized in order to accomplish such a task.

2b. Review and summary

The TCT concept was inspired by the quest to understand the fundamentals, answer the questions, and fulfill needs identified by the issues outlined in Chapter 2a. It became apparent that existing project development tools, such as design guides, design exception procedure, and benefit/cost ratio methods didn't fully address all issues and weren't well suited to finding optimal answers. Fund allocation schemes proved to be susceptible to predisposition by their inputs, contained internal biases, provided inverse incentives to recipients, and produced erratic results. In additional, lack of ability to identify appropriate funding for individual roads has stymied a long sought rationalization of Iowa's roads.

Issues such as trucks versus trains, the highway lobby accusation, ISTEA implementation, and the Des Moines Register critiques of county pavements showed a need for a better way to frame issues and conduct dialogs. Problems were often approached with a restricted, “roads are the system” perspective, overlooking the scope of the total system.

Such issues suggested a need for improved methods of analysis and it didn’t seem that conventional practice could be incrementally refined to accomplish that goal. And there appeared to be a need for methods that could work at both network and project scales, help designers better understand the tradeoffs of different design levels, and be understandable to the general public.

Table 2-6 summarizes the findings of Part 2a for ease of review:

Table 2-6 : Summary of TCT background issues and evaluation of conventional practice

No.	Issue or situation:	Questions and concerns:	Impediments to finding answers:
1	E23Y Paving petition	a) How to find optimal design level? b) How to compare merits of alternate solutions for same need? c) Which is better: to implement inexpensive improvements now or wait to build a higher design later?	a) Decision aids helped justify any design level – but didn’t identify the best one. b) Methods weren’t structured for comparing alternates. c) No documentation of how design guides were set up.
2	<u>Transportation and Iowa’s Economic Future</u>	a) How much money *should* go to any particular road or jurisdiction? b) Should funds be proportionately divided on the basis of relative factors? c) What factors, in addition to total traffic, ought to be considered when distributing road revenues?	a) No truly non-proportional methods available. b) Existing analysis processes not sufficient for finding optimal choices. c) Current practice tends to rely on technical measures instead of economics.
3	Design exception analysis	a) How to balance value of safety benefits with cost of achieving them? b) What is the incremental safety benefit of a partial improvement in design? c) Would measurement of differences in non-accident user costs affect the results?	a) Method didn’t account for time value of money b) Relationship between degree of improvement and amount of accident cost reduction not well established.

Table 2-6, continued.

No.	Issue or situation:	Questions and concerns:	Impediments to finding answers:

4	ISTEA implementation	a) Could lack of regional planning really be producing an inadequate rural road system? b) Was there a bias favoring roads over other transportation modes? c) Were massive new public participation efforts needed? d) If conducted, how could citizen involvement processes be structured to produce useful results and participant satisfaction?	a) Suggested planning criteria tended to rely on technical measures and point based prioritization. b) Difficult to compare economics of different modes. c) Hard to involve citizens except when project directly affected them. d) Typical public involvement processes didn't truly engage citizens or succeed in getting them to take ownership of outcomes.
5	Minimum standard county roads	a) How to objectively select a true minimum standard level of service? b) If a minimum standard was determined, what funding should it receive? c) How could a particular standard and funding level be justified and communicated to legislators?	a) Difficult to develop a consensus using purely technical methods. b) No methods based directly upon economic analysis. c) No accepted tools for computing fundamental, non-relative financial need
6	Quadrennial Needs Study	a) How should road use taxes be distributed between systems and jurisdictions? b) How can input data and analysis process biases be prevented? c) How can stable funding levels be achieved?	a) Existing procedure unpredictable, hard to follow, contained some bias, and presumed unlimited funding. b) Existing method relied exclusively on proportional distribution. c) Process not scalable. d) Some input data too old. e) Simulation started from what was already in place -- not what *should* be in place.

Table 2-6, continued.

No.	Issue or situation:	Questions and concerns:	Impediments to finding answers:

7	Comparison of rail and trucking industries	a) Hard to compare economic performance of trucks with railroads because cost of capital investment in roads not included in truckers' rate of return determination. b) How would road transportation economics change if the cost of capital were charge out to drivers?	a) Road finance practice doesn't explicitly tack capital asset value of road system. b) No clear way to determine what proportion of total capital investment should be assigned to trucks.
8	Popular concept of highway lobby	a) Is there over-investment in highways and, if so, what is the cause? b) Does the public need to be made more aware of transportation economics? c) How could one determine and defend the optimal investment level for roads?	a) Existing methods don't fully incorporate economics into decision making. b) Convention procedure divides money so it can be spent – rather than determining what should be spent.
9	County road critiques	a) How should road agencies respond to repeated media attacks? b) What type and format of information would best tell "the other side of the story."	a) Existing methods more technical than economic based. b) No good way to involve public in decision process.
10	Sufficient ratings and Management systems	a) What sequence of construction and repair will best serve society? b) How can funds be deployed for optimal results?	a) Use of abstract ratings leads road officials to manage assets more than to optimize transportation. b) Ratings and management systems lead to "roads are the system" perspective that overlooks larger system issues.

Table 2-6, continued.

11	Functional Classification and Transfer of jurisdiction	a) Could a viable road system realignment process be restored? b) Should road revenues be allocated by road segment? c) How could one determine the best amount to spend on any individual road Chapter?	a) Current practice doesn't provide convenient method for determining financial need of individual roads. b) Existing RUTF allocation process fails to adjust funding when transfers occur.

2c Summary of needs

Part 2a presented the TCT research project's source issues. Part 2b reviewed and summarized questions, concerns, and impediments identified by Part 2a's sub-sections. This part of Chapter 2 consolidates the identified needs into broad classifications and identifies what changes, improvements, or innovations would help improve the situation. Table 2-7 lists the general categories open to improvement, cross references them back to the items in the *Impediments* column of Table 2-6, and then lists the potential solutions.

Table 2-7: Summary of major need areas and potential remedies

ID	Generalized needs from 2a and 2b	Table 2-6 impediments cross reference	Potential remedy or solution method
1	Inadequate assessment of economics.	2c, 3a, 4b, 5b, 5c, 7a, 8a, 9a, 10a	Develop analytical methods that use economic fundamentals.
2	Perspective too limited	4a, 7b, 8b, 10b, 11b	Develop decision aids that work from total systems perspective.
3	Base data and/or process logic may bias outcomes.	5a, 6a, 6b, 6d, 6e	Eliminate pre-dispositions by revising process.
4	Existing decision aids not set up to assist seeking optimal level of service -- or to compare merits of alternates.	1a, 1b, 2a, 2b	Develop formal tools for seeking optimal options and evaluating tradeoffs.
5	Difficult to present transportation issues to the public and obtain informed, objective participation in the decision process.	1c, 4c, 4d, 9b	Create process where all public values can be incorporated into a model understandable to average citizens.
6	Methods and processes not scalable	3b, 6c, 11a	Devise a process that will work equally well at both the network and single project levels..

Thus, the eleven source issues contributed to the identification of six major areas of need.

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Chapter 3

TCT CONCEPTS and THEORY

3. TCT concepts and theory

3a – Introduction

This Chapter presents and describes the TCT concepts developed to answers the needs identified in Chapter 2.

3a-1 Objective

The objective of this part of the project was to define a concept with sufficient precision to enable creation of an analytical model. Another goal was to provide a detailed theory to serve as a foundation for future evaluation and refinement.

3a-2 Organization of this chapter

The derivation of concept and theory is presented in the following sequence:

Section 3b identifies and discusses key words that require precise definition within the scope of   the proposed TCT concept.

Section 3c states and comments on TCT's four fundamental premises.

Section 3d formally presents the theory in an semi-algebraic form of notation.

Section 3e provides a detailed analysis of each Section of the theory.

Section 3f evaluates the fitness of the theory to fulfill the needs noted on Section 2c, Table 2-7.

Section 3g explores the characteristics needed to model the theory.

Section 3h concludes with miscellaneous observations on the theory as a whole.

3b - Special Definitions & concepts

This section enumerates and discusses several key words that need to be given very specific meanings within the context of TCT analysis. The extra precision is required because the words have multiple meanings and are often used interchangeably in routine discourse.

3b-1 Cost

COST is the real, economic value of things that are consumed or given up in order to achieve an end – and is usually measured in dollars. Within TCT, the term will mean absolute total cost, not incremental, marginal, or differential costs.

3b-2 Price

Within TCT, PRICE should be defined as the *perceived* cost of attaining a goal. In other words, it is a subjective assessment of real COST. People compare PRICE to value returned in order to make economic choices. PRICE is a combination of level of effort required, monetary expense, value of time used, and depreciation of assets employed.

3b-3 Charge

A CHARGE is the dollar amount that a supplier demands in return for providing a product or service. It is a mechanism for recovering the COST of the item sold. (In everyday speech, CHARGESs are often referred to as PRICEs – but the two terms must be kept separate in TCT.)

3b-4 Benefit

BENEFIT is the *perceived* value of a product or service to the party who acquires it. In some cases, BENEFIT is nearly equal to PRICE while in others it greatly exceeds the PRICE paid. If the BENEFIT of something is less than the PRICE required to obtain it, people usually elect not to.

3b-5 Relationships between the terms

COSTs and CHARGEs are items that are able to be accurately and objectively determined in monetary units -- and will be found to be the nearly the same by all parties who might seek to measure them.   PRICES and BENEFITS, on the other hand, are much more subjective, incorporate intangible factors along with monetary value.   Thus, they vary greatly from person to person and aren't amenable to accurate measurement.

The following example illustrates how the four terms are related to each other:
The COST of producing refining and delivering a gallon of gasoline might be $0.60. But when a motorist purchases fuel they will be CHARGED $0.99 per gallon. This is because the fuel station CHARGES an additional penny to sell the gallon and is required, by state law, to add a road use CHARGE of $0.38. The latter amount partially recovers society's COST of building and maintaining roads. Vehicle owners tend to buy their fuel at whatever outlet offers the least CHARGE. But they'll pay more at a nearby station if the time and distance "price" of going to the cheaper outlet outweighs the cash savings to be attained. And, if their car will transport them 20 miles per gallon and they value of such travel at $0.10 per mile, they'll perceive a BENEFIT of $2.00 per gallon used

Highway economy studies quite often try to compare alternates by computing the ratio of total BENEFITS estimated to result from the improvements with the CHARGE paid to have a contractor improve a road. TCT will not use this approach. First, because BENEFIT is a highly subjective measure that is difficult to quantify. Second, because the CHARGEs paid to secure the improvements probably doesn't include all of society's COSTS. Taking ratios of such uncertain, incomplete values cannot provide completely objective results.

Instead, TCT will examine and compare road improvement options by computing the total economic COST society must bear for the transportation activity it generates. This number can be determined with much greater accuracy and reliability than PRICE or BENEFIT – and is generally non-subjective.

3c - Fundamental premises

This section outlines four basic premises that have come to be the basis for the TCT concept. They were developed over a number of years, by a process of successive refinement, to form a clear conceptual basis to work from.

3c-1 Road based transportation is produced by a complex system

Analysis should start from the perspective that road based transportation is produced by a complex, multi-faceted system composed of roads, vehicles, people, terminals, parking, and information, and more.

3c-2 System capacity and activity results from market forces

Market forces find equilibrium points between PRICEs and BENEFITS that determine both capacity and utilization. First, society and individuals acquire or build transportation capacity in response to the perceived benefit of doing so. A secondary benefit versus price perception governs how much of that capacity gets used at any point in time.

3c-3 A total economic cost results from the system's activity level

The TOTAL COST of TRANSPORTATION, or ***TCT***, is the dollar value of all things consumed, given up, or permanently reserved to produce both capacity and activity. This includes land, time, materials, energy, human labor, and natural resources.

3c-4 Road are improved to reduce the total economic cost of transportation activity

The economic objective of building and improving roads should be to minimize society's total COST of transportation for any given level of transportation activity.

3d - Formal expression of the TCT theory

This section presents the TCT theory in a semi-formal form of notation. It is intended to amplify the ideas embodied in the four core premises and to provide a foundation upon which analytical methods can be based.

3d-1 Road Based Transportation System [RBTS]

The RBTS <is composed of> [VEHICLES] + [ROADWAY NETWORK] + [DRIVERS]
+ [TERMINALS] + [SUPPORT SYSTEMS] + [INFORMATION]
+ [LEGAL / INSTITUTIONAL / FINANCIAL FRAMEWORK]
+ [COMMUNICATIONS] + [PARKING] + [& more]

3d-2 RBTS activity level

The activity level, (total amount of travel and shipping), of the RBTS system, is the result of market forces. It is usually measured in terms of Vehicle Miles of Travel, or VMT.

System capacity

CAPACITY$_{VMT}$ = f([Road network size & quality], [vehicle count & performance],
[quantity and skill of drivers], [size of support systems])

We increase capacity whenever the BENEFIT of doing so is perceived to exceed the PRICE of doing so. Lane-miles of roadway traffic capacity gets expanded via several market force mechanisms: government adds to the public road system to meet citizen demands, boost economic activity, and reduce risk. Private land owners build driveways and internal roadways to obtain the benefit of enhanced land use. Sub-developers pave new roads in order to make a profit by selling new lots.

Vehicle capacity decisions, however, are made almost entirely by individuals. Each buyer weighs the price of acquiring a vehicle against the benefit of being able to access and use the roadway capacity. Vehicle fleet size expands in proportion to population growth and in response to the balance between prices and benefits of driving.

Support system size decisions are made by a multitude of different parties. Retailers and businesses add parking as needed to accommodate customers and employees. Drive up windows and services are added when their business benefit exceeds the price of installing them. Improved terminals are built to reduce the time required to load or unload cargo. Logistics planning centers are developed to increase the efficiency with which private fleets operate upon public routes.

The relationship between the three main components of capacity, (vehicles, roads, and drivers), is dynamic and changes over time. Vehicle counts increased ten percent faster than licensed drivers over the last thirty years. (FHWA, 1995). More dramatically, the number of vehicles grew by more than fifty percent between 1973 and 1996, while total route mileage of the road network rose only 3.0 percent. (AASHTO, 1996). Between 1973 and 1993 population grew by 22 percent while the number of licensed drivers jumped 42.5 percent and total travel increased 74.9 percent. (FHWA, 1995)

Capacity utilization

$$\textbf{UTILIZATION}_{\mathrm{VMT}} = \mathbf{g}(\mathbf{[RBTS\ CAPACITY}_{\mathrm{VMT}}\mathbf{]}, \mathbf{[}\text{Per mile price}\mathbf{]}, \mathbf{[}\text{Per mile benefit}\mathbf{]})$$

System utilization decisions are made after capacity has been built or acquired. Drivers appear to make their choices by comparing the benefit of taking a trip with the time, en-route expense, and fuel prices inherent in the travel. Likewise, shippers mentally combine carrier charges, in-transit loss & breakage, and time lost while-in-shipment to figure a total price when choosing between different modes of shipment. Significantly, neither drivers nor shippers appear to incorporate the true, full cost of transportation into their decision making. Individuals often do not explicitly consider the direct per mile cost of their vehicle's purchase price in making travel plans – only the incremental price of operating it. And since government doesn't attempt to charge and recover the cost of the capital invested in the road network, shippers don't factor that cost item into their deliberations at all. Likewise, parking area cost are often recovered through charges for merchandise or services in lieu of a direct charge per vehicle-hour of storage.

3d-3 Total Cost of Transportation [TCT]

$$\mathbf{TCT}_{\text{Activity}} = \mathbf{SUM(\ [}\text{Fixed Costs}\mathbf{],\ [}\text{Distance dependent costs}\mathbf{],\ [}\text{Time dependent costs}\mathbf{])}$$

Per the definition presented in Section 3b-1, the Total Cost of Transportation, or ***TCT***, is the dollar enumerated value of things that are consumed, given up, or permanently reserved in order for transportation to take place. Such items can be classified into three categories:

a) FIXED costs are those that are the same regardless of how much or how little activity there is.
b) DISTANCE costs are those that vary directly with the total number of miles of travel that take place.
c) TIME costs vary directly with how much time is required to take a trip or deliver a package. (Thus time costs are inversely related to speed of travel.)

Fixed costs arise mostly from the public road network, and also from terminals, and parking facilities. Distance based costs include vehicle depreciation, fuel consumption, tire wear, and road maintenance expenses that are proportional to traffic volume. Time costs arise out of wages paid to drivers and travelers, plus the value of goods in shipment

3d-4 Road improvement economics

$$\mathbf{CHANGE}_{\text{TCT}} = \mathbf{INCREASE}_{\text{Fixed Cost}} - \mathbf{DECREASE}_{\text{Distance Cost}} - \mathbf{DECREASE}_{\text{Time Cost}}$$

The final TCT premise is that the economic objective of improving the road network is to reduce or minimize the total economic cost of the Road Based Transportation system -- at its current activity level. This is generally accomplished by adding new capital improvements. This increases the system's fixed costs but enables a decrease in the distance and time based costs.

3e - Technical analysis

This section expands on the theory of Part 3d and analyzes RBTS operations and economics graphically. To do so, it presents and uses numbers and values that approximate real world circumstances.

3e-1 Description of Road Based Transportation System

The TCT concept views road / motor-vehicle transportation as being produced by a complex, multi-component system composed of public and private assets. This section provides more detail on that perspective and describes its primary characteristics.

3e-1.1 Components

Figure 3-1 below enumerates most of the components of the Road Based Transportation System, (RBTS). This list is not fixed and stable. New components get added as technology and society advances.

Figure 3-1

RBTS ==

Right-of-way, Grade, Structures, Pavements, Traffic controls, Entrances, Parking lots, Truck terminals, Loading docks, Drive-up windows, Drive-up ATM's, Cars, Pickups, Campers, Trucks, Service Stations, Auto dealers, Car plants, Road contractors, Parts stores, Car washes, Auto insurance, Wreckers, the Dept. of Motor Vehicles, Motor vehicle code, Map companies, Auto loan firms, Junkyards, Logistics centers, Dispatchers, Quarries, Motels, Law enforcement, Lighting, Pedestrian bridges, TV ads, Cars for sale classifieds, Bill boards, Driveways, Garages, Parking lots, Driver's education, Highway research facilities, Safety programs, Business and professional associations, Automotive R&D, Credit card processing systems, Truck stops, Cellular phones, etc.

3e-1.2 Characteristics

The RBTS is not controlled by any single sub-group. Ownership is dispersed among many different groups and organizations. Each is affected by the others but remains free to act independently of them. Capacity grows more or less constantly. Activity varies by time of day, day of week, and time of year.

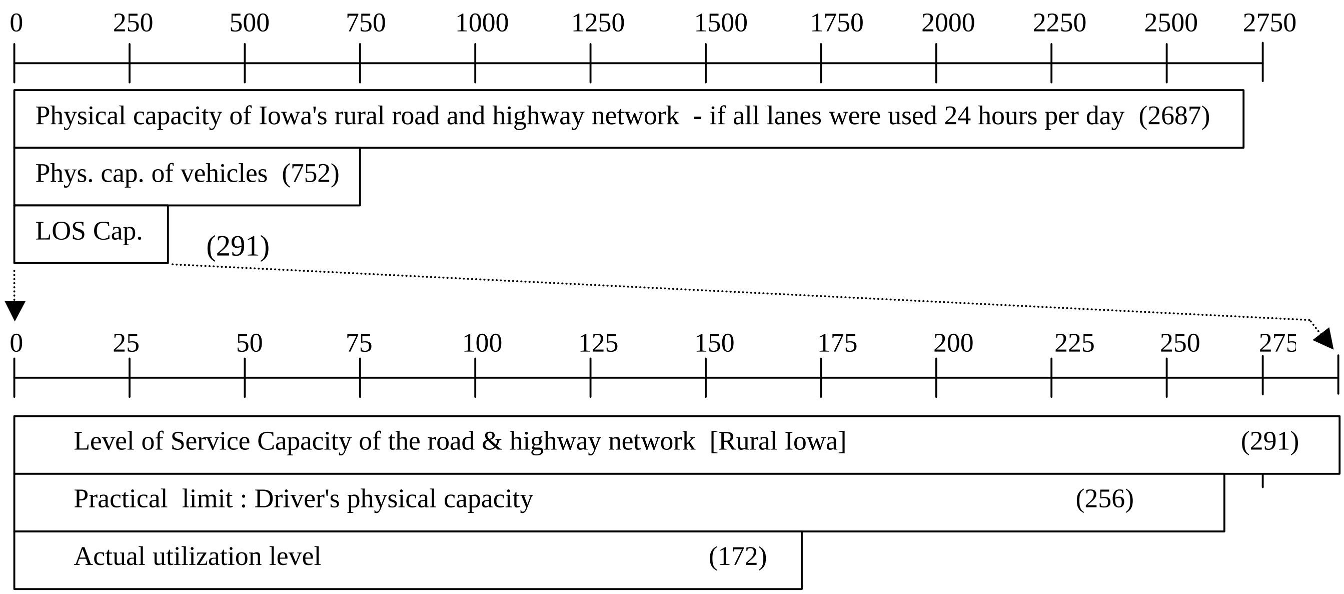
3e-2 System activity

The total amount of travel and shipping is based first on overall system capacity and second on the degree to which the capacity gets used.

3e-2.1 Capacity

The maximum capacity of the RBTS is established by roadway lane-mile traffic carrying capacity, vehicle operational capacity, and the physical abilities of drivers.   It is also affected by terminal, en-route, and parking capacities.   Figure 3-2 compares capacities:

Figure 3-2   RBTS Capacity Analysis   [100 Million VMT per year] [Rural Iowa]



(The data used to produce Figure 3-2 can be viewed in Tables 3.1a, 3.1b, and 3.1c at the end of this section).

It can be seen, from inspecting the chart, that driver capacity serves as the practical upper limit for RBTS activity. Even though road and vehicle capacities are greater, they cannot be used in excess of driver capability. And while roads have an enormous physical capacity, their adequacy is usually judged according to how well they handle peak traffic loads. Thus, the level-of-service capacity figures are set much lower than maximum physical capacity

The market forces that determine the size and capability of the system components listed above are complex but their result is quite simple: steady, continuing growth. Political, legal, and economic forces induce the public sector to build and maintain roadway capacity. Population growth, age distribution, economic and social forces set the number of active drivers. The benefits of access to the road network, independent choice of route and time, cargo capacity, personal comfort, personal style, and many other factors guide auto and truck purchases.

Taken together, these forces result in capacity growing between 2.0 and 3.0 percent per year. In the last 30 years, vehicle and driver capacity growth has been the primary driver of system potential. From 1961 to 1993, total annual VMT in Iowa increased from 11.471 x 10^8 to 25.396 x 10^8. (Iowa DOT, 1993) This 121 percent increase indicates an average annual growth rate of 2.68 percent.

Future growth may be slower:

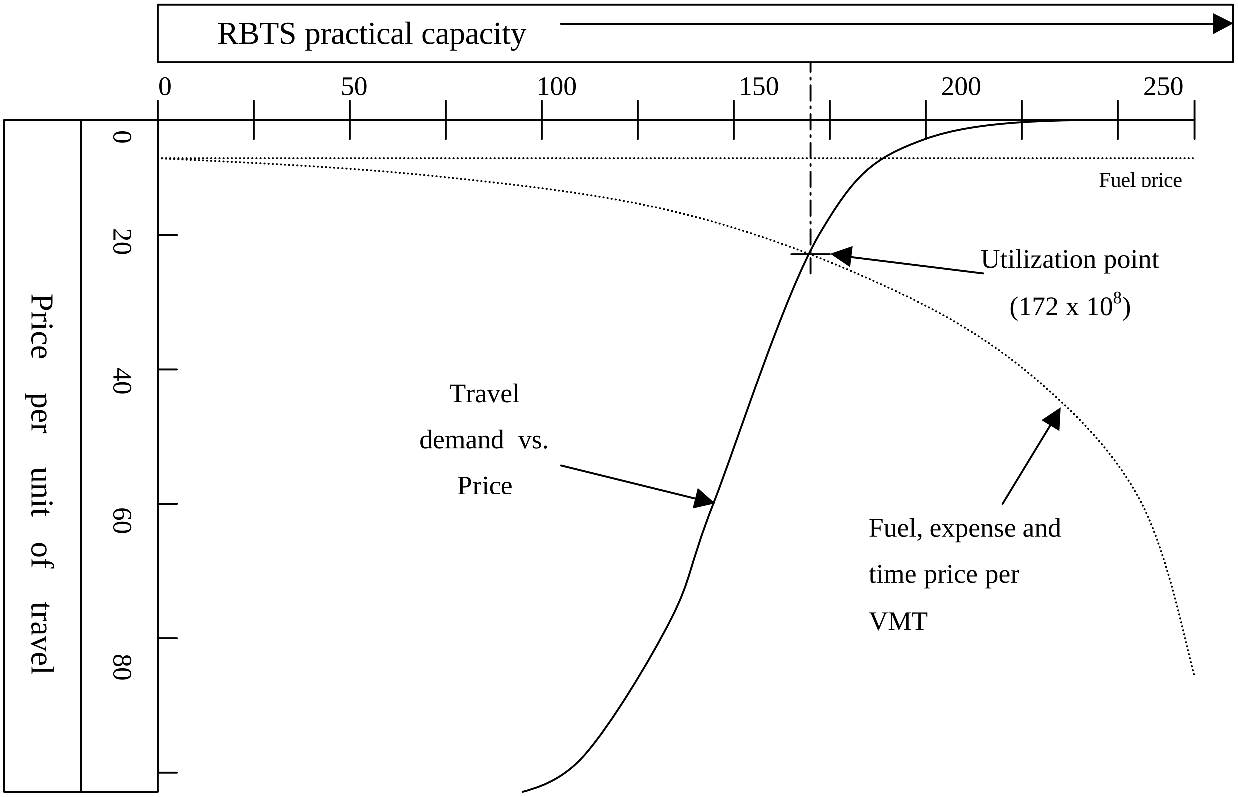
- In that '61 to '93 time period, despite a static state population, the number of people of driving age increased due to the changing age distribution within the state. Plus the percentage of eligible people actually holding licenses grew and each driver increased their per-year travel.
- We now approach an era where the driving age population will stabilize and even decrease. Since almost everyone who could be licensed is and a significant number will soon begin driving fewer miles per year as they age, practical system capacity will likely grow more slowly in future years than has been the case since 1960.
- In the same time period, Iowa went from having substantially fewer cars than drivers to where there the number of each is nearly equal. Future growth in the vehicle fleet won't boost activity a lot, because there won't be enough drivers to operate them all.

Despite the any system-wide leveling off that may occur, internal shifts of traffic load from one road type to another will probably continue to rearrange traffic flow patterns.

3e-2.2 Utilization

The previous section indicated that driver capacity sets a practical upper limit on system activity. Under current circumstances, society appears to be using the system at about two thirds of that maximum level. Figure 3-3 illustrates the market force dynamics that determine how much capacity gets used:

Figure 3-3 RBTS Utilization market force diagram



The chart's horizontal axis represents the activity level in terms of 100 million VMT per year. The vertical axis indicates the price per VMT.

- The first curve, (shown as a dotted line), relates the price of using capacity to the level of activity. It includes charges for fuel, en-route expenses, (such as tolls, parking fees, food, and lodging), and the perceived value of the driver/passenger's time. Fuel price and tolls don't vary much with the speed of travel, but time prices do. So the curve rises more rapidly at higher traffic volumes – reflecting the fact that increased vehicle density leads to congestion, slowing traffic down.
- The second curve, of travel demand vs. price per mile of travel, VMT, illustrates, in a general way, how capacity utilization likely varies with perceived price. Society appears to operate in a somewhat stable middle range where activity doesn't change much, regardless of price. At very low prices, capacity utilization would begin to climb rapidly, as people began to use Road Based Transportation more intensively and began substituting it for other ways doing business. Conversely, at substantially higher prices, society would cut back on travel and begin finding ways to make do with less of it.

- At any given time, the two curves cross at a point that coincides with the current activity level. In Iowa, the interaction between the two measures has resulted in a rural traffic volume of about 172 x 10^8 VMT per year recently. This is approximately 67 percent of the estimated practical capacity of 256 x 10^8 VMT per year.

A number of additional observations apply to Figure 3-3:

- Since the travel demand curve is strongly influenced by vehicle and driver capacities, it tends to shift to the right year by year. This means that travel will generally increase – even if price levels rise, too.
- It takes substantial price increases, such as experienced in recent years, to reach the point where activity growth is slowed or halted.
- Drivers tend to rate the price of their time as being more dear, (perhaps three to four times), as the price of fuel and expenses.
- Anything that reduces time of travel or load/unload time works as a price of transportation reduction and thereby causes a marginal increase in activity.
- TCT should model overall capacity, its rate of growth, and the utilization thereof

3e-3 Total Cost of Transportation

For any level of activity, the Total Cost of Transportation, or ***TCT***, is the sum of all economic resources consumed, given up, or set aside to produce the travel and shipping therein.

3e-3.1 Cost types & categories

There are three types of cost to track: fixed, distance based, and time based. Fixed costs are items whose magnitude is independent of traffic levels. Distance costs are directly proportional to the distance traveled or total vehicle miles of travel. Time based costs depend on the speed of travel, so they tend to increase more and more rapidly and traffic counts increase.

The goal of TCT is to analyze and account for all types of costs from all sources. To that end, a number of cost source categories have been identified. Each category contains fixed, distance, and time cost elements:

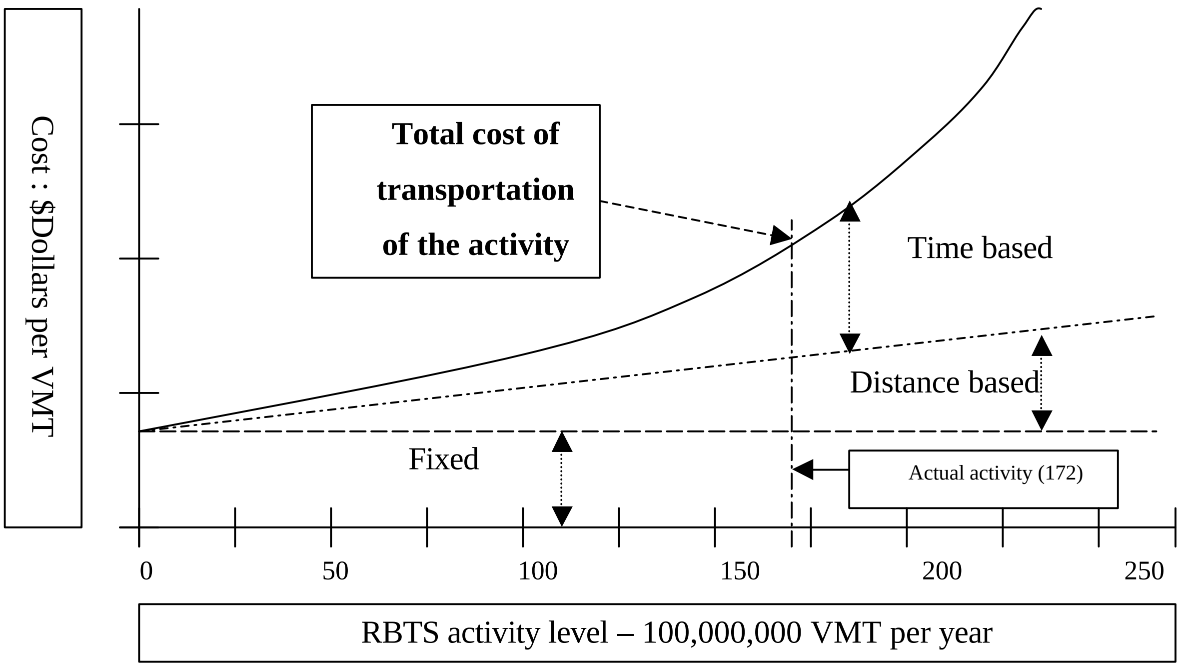
Road network costs	Vehicle fleet costs	Human resource costs
Accident costs	Business/Economic costs	Social/Environmental costs

It's also be appropriate to include a "cost offset" category to reflect instances where the existence of the road based transportation system enables society to decrease other costs and/or to boost the economic value of adjacent land.

3e-3.2 TCT versus activity level

Figure 3-4 illustrates how the TCT varies in relation to activity level:

Figure 3-4 Total Cost of Transportation vs. Activity Level

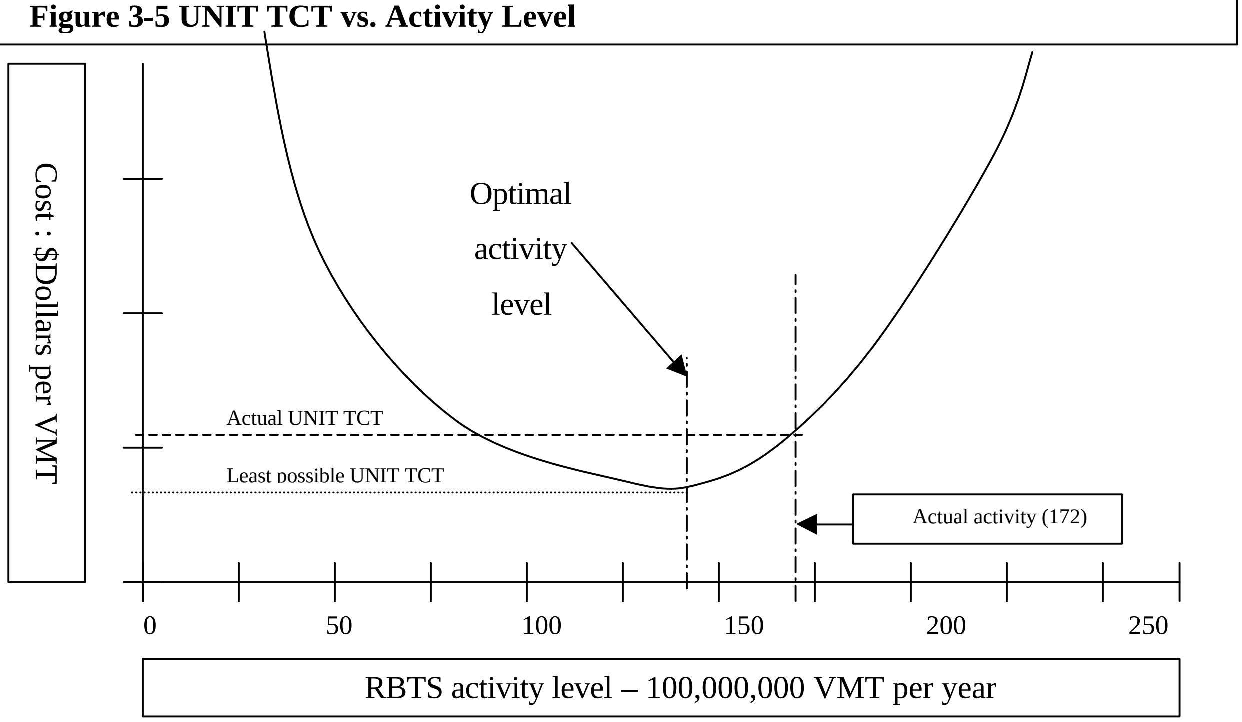


Note that fixed costs remain constant, distance costs plot into a straight, upward-sloping line, and time costs follow an upwards trending curve. The sum of all three indicates the total cost of transportation for all activity level. Building roads or adding cars to the fleet increases fixed costs but can decrease distance and time expenses. However, extreme over-investment could result in the fixed cost gain exceeding the distance and time-savings – which would increase the TCT.

3e-3.3 Unit TCT vs. activity level

To permit better understanding of TCT versus activity level, Figure 3-5 presents a sample graph of cost per VMT for each activity level:

Figure 3-5 UNIT TCT vs. Activity Level



When a full TCT value is divided by its associated activity level, the result can be called the Unit Cost of Transportation, or UCT. This value, expressed as dollars per VMT, starts out high and initially decrease inversely with increased traffic levels – as the fixed costs get spread across more and more vehicle miles of travel. But, since distance and time costs rise as traffic grows, they eventually overtake the fix cost reductions and cost the UCT values to begin rising. As a result, there is a point of minimum UCT that identifies the OPTIMUM or least cost activity level for current system capacity.

If capital investments are made to increase capacity, such as building more roads or acquiring more vehicles, the unit fixed cost component increases while the other two decrease. This can visualized as shifting the UNIT TCT curve the right. Inspection of the curve thus suggests the following:

- As long as the actual activity level is greater than the optimum level, capital investments in capacity will reduce the overall TCT: because the unit cost per VMT at the current activity level will be decreased.

- If the system is operating at the optimum activity level, capital improvements will shift the least UNIT TCT point to the right of the actual traffic volume point. This will result in an increased UNIT TCT, causing total costs to rise. So road improvements or fleet size increases are of benefit only up to the point where they cause the least unit TCT point to match the existing activity level. Improving a system beyond the least cost point would be counter-productive.

- As actual activity grows, it advances farther and farther to the right of the least UNIT TCT point. The total potential cost savings from making a capacity improvement increases non-linearly, rising faster and faster as the activity differential expands.

3e-3.4 Interrelationships between price, activity, and cost

Price versus benefit establishes the actual activity level and the activity determines the unit TCT. Figure 3-6 illustrates this relationship:

Figure 3-6 Relationship between PRICE, DEMAND, and TCT

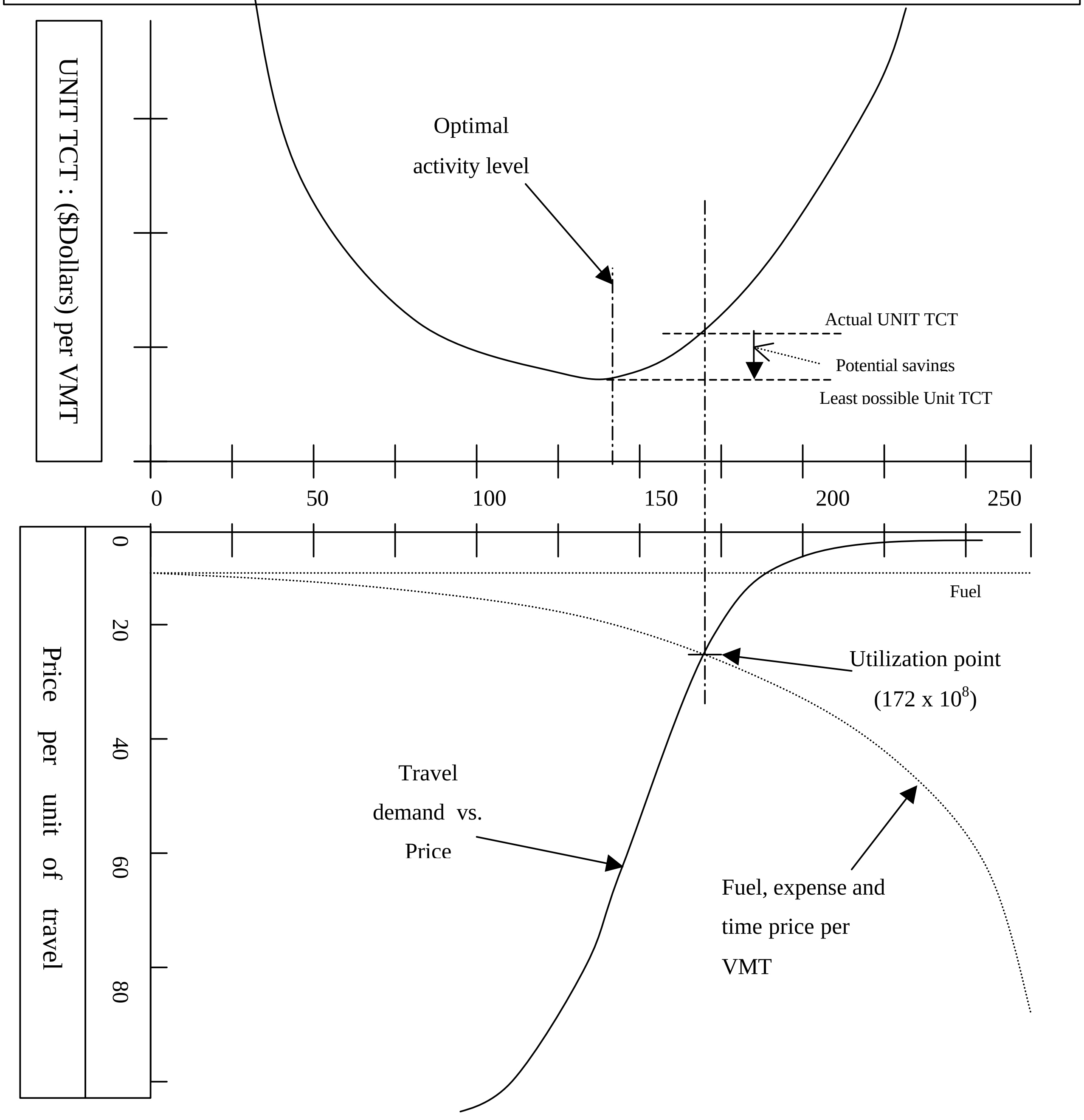


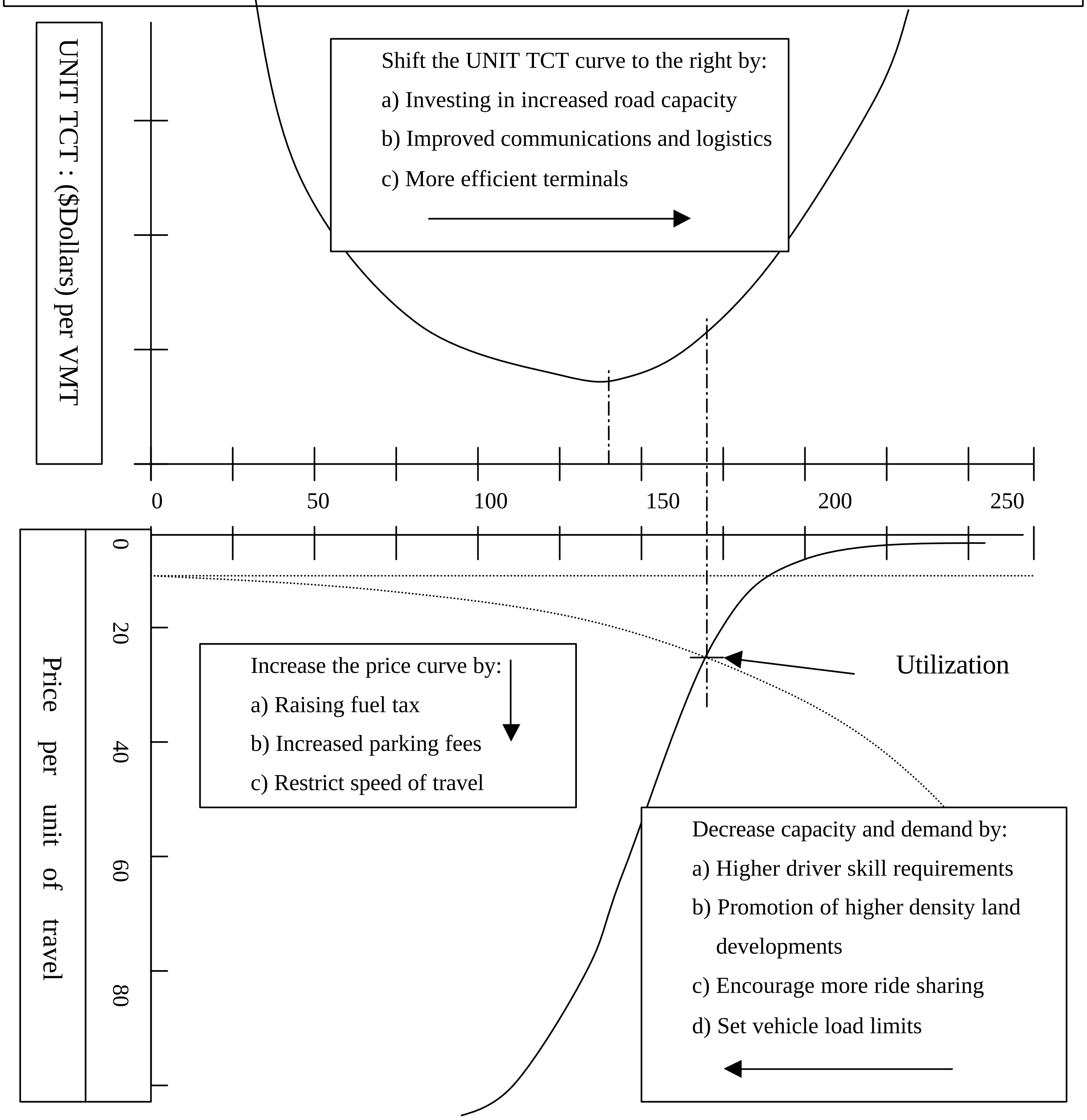
Figure 3-6 provides insights into ways that RBTS size, activity, and economics can be impacted:

- Anything that increases the price per VMT will result in a net decrease in activity – shifting actual levels closer to the optimum point and reducing total cost. Conversely, a reduction of price can induce greater activity and boost TCT.
- Since capacity grows more or less constantly, activity levels are always pulling ahead of the current optimum.
- This eventually creates a sufficient cost savings potential that it becomes advisable to readjust the system – usually through capital investments to increase capacity.

3e-4 Methods for reducing Total cost of Transportation

Given the interrelationship between price, activity, and cost, there are a number of different ways to keep TCT as low as possible. Figure 3-7 illustrates the potential options:

Figure 3-7 Options for reducing UNIT TCT



To reduce TCT, you can a) take actions that shift the unit TCT cost curve to the right, b) increase the price curve by charging more for fuel and roads, c) induce a decrease in travel demand – thus reducing utilization. The first option is the only one within the direct power of road agencies. The others are controlled by the private sector, the federal government, state governments, and land use.

Note that the system can also be impacted by new technology: if intelligent transportation systems research someday enables cars to safely operate at higher speeds and less headway, both the transportation demand and unit TCT curves would be shifted right while the price vs. activity curve would be decreased. This would essentially increase capacity, boost utilization thereof, and probably decrease both unit and total TCT.

3e-4.1 Available methods

This section highlights the various mechanisms by which society may impact or adjust the price – demand – cost relationships of the RBTS.

Technology

Technological improvements can reduce costs, decrease prices, and boost capacity.

- Advances in engine design have substantially reduced fuel costs – reducing both cost and price. (Price is reduced when cost is reduced)
- Safety feature like airbags, seatbelts, and anti-lock brakes have helped cut accident costs.
- Cellular telephones have reduced the "communications price" incurred while traveling – but may also be causing accident rates to increase.
- Computer controlled signal systems help streets carry more vehicles per hour before congestion sets in.
- Improved telecommunications systems may actually reduce the need for travel.

Change in value systems

If the perceived value of time spent traveling were to increase, drivers would immediately cut their utilization of capacity. Or, if it became fashionable to build compact neighborhoods with most stores in walking distance, the public would not demand to use automobiles to accomplish all life tasks.

Rules and regulations

Society's self imposed rules affect how the system operates. Speed limits set minimum travel times. Age limits on drivers control how many there are. Motor vehicle codes help determine minimum vehicle costs and maximum loads per trip.

Pricing

Given the rather inelastic relationship between price and demand, changes in price won't affect system activity levels or costs very much. However, the more closely the perceived, per mile price-of-travel matches the real unit cost of transportation, the closer the system will operate to the optimum level.

Logistics planning

Logistics planning consists of gathering information, analyzing it, formulating a vehicle operations plan, and then instructing drivers how to operate and what routes to take. This process helps maximize efficient use of existing roads, vehicles, and drivers. Private carriers utilize logistics to optimize their operations. Highway authorities use it to control and optimize the flow of traffic within the road network.

Road improvements

Construction of new links and lane capacity enhancements are the oldest and still one of the most important methods for reducing TCT.

3e-4.2 Road Improvement economics

The remaining focus of this research project will be on how road improvements help reduce or minimize TCT. This is the only significant tool most highway agencies are able to apply to the system. The majority of the other factors cited in Section 3e-4.1 are controlled by other sectors of society: business, legislative bodies and individual citizens.

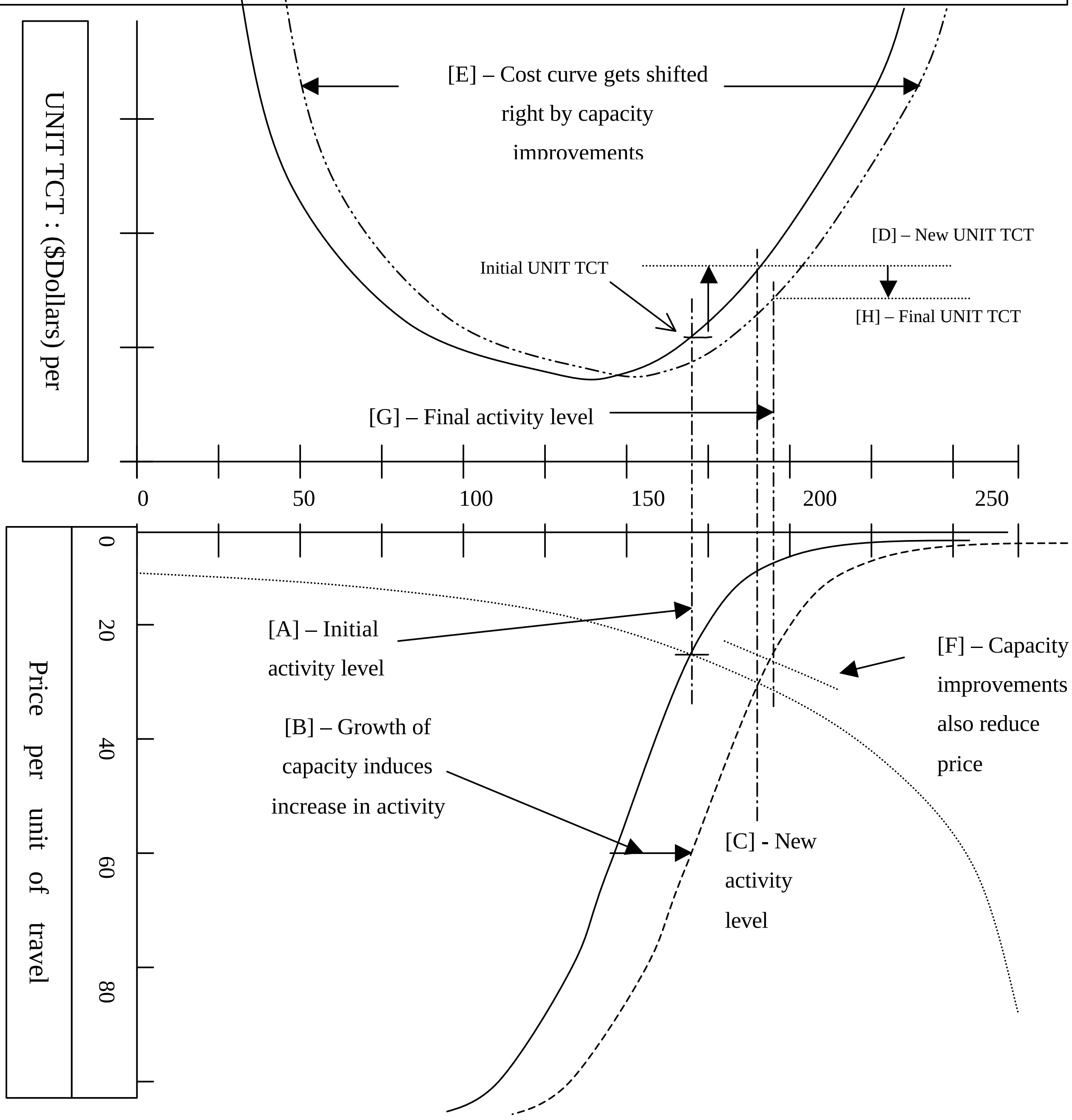
Basics

The economic equation of deciding road improvements is this: a project is justified if it can decrease the road based transportation system’s overall TCT level. When multiple projects are under consideration, they can be prioritized on the basis of how much they reduce TCT per $1000 spent.

Detail

Figure 3-8 outlines how road improvement projects fit into the price – demand – cost model of TCT. This section takes note of every single item involved, so it's more complex than would be required in many decision making circumstances.

Figure 3-8 Analysis of using road improvements to reduce TCT



Note : the proportions of the diagram shown above have been deliberately exaggerated to assure that all items would be visible.

With reference to the circled letters on the chart:

a) At any given time price and demand interact to establish the degree to which system capacity is utilized, resulting in a specific activity level.
b) Due to population growth and increases in system capacity, the demand curve continually shifts to the right.
c) This leads to increased system activity levels.
d) Presuming actual activity is above the optimum, such increases boost the unit and total TCT of the system.
e) By constructing road improvements, the cost curve is shifted to the right, reducing TCT – though probably not back down to its original level.
f) The road improvements also slightly decrease the perceived price of travel, causing the activity level to marginally increase beyond the year-to-year growth.
g) and h) The intersection of the final activity level with the adjusted cost curve determines the final unit and total TCT values.

The net savings can be computed as follows:

$TCT_{savings}$ = [Unit $TCT_{original\ curve}$ x VMT_c] – [Unit $TCT_{after\ project}$ x VMT_h]

Modes of action

Road improvements impact cost and price in a number of ways. Figure 3-9 lists six ways by which distance and time costs are reduced via improvements to the road network component of the RBTS:

Figure 3-9

No.	Item	Remarks
1.	Decreased effort	Vehicles experience less rolling resistance on improved roads, and can move with less wear and energy consumption per mile.
2.	Decreased travel distances	As more links are built, drivers are able to find shorter pathways between origins and destinations.
3.	Decreased travel time	Better roads permit higher speeds, more passing opportunities, fewer stops, and less congestion.
4.	Fewer trips required	Improved roads and bridges permit larger vehicles to carry heavier loads. This reduces the number of trips required to move a given quantity of freight.
5.	Decreased uncertainty	Better roadways, higher level maintenance, and route redundancy increase the likelihood of on-time arrival – reducing the need to stockpile materials or make contingency shipments.
6.	Decreased risk	Improved roads have fewer accidents and produce less en-route loss or breakage.

3f - Theory evaluation

The proposed TCT concepts and theory appear capable of answering most of the needs identified in Section 2, Table 2-7. Table 3f(1) presents the author's assessment of how well each goal can be met:

Table 3-10 Evaluation of theory's value in responding to identified needs.

No.	Description	Estimated degree to which need is answered by theory.
1	Need to base analysis and decision making on economics	95%
2	Need to developer broad, total system perspective.	95%
3	Need to reduce or eliminate built in biases or pre-dispositions.	90%
4	Need tools that assist in identifying optimal solutions.	90%
5	Need tools that enable evaluation of tradeoffs between two design level options for a particular traffic level.	90%
6	Need a process that is open to inspection by anyone interested.	85%
7.	Need a process that non-professionals can understand.	75%
8.	Need a scalable method of analysis.	75%

While these assessments are admittedly subjective, the concept and theory appear capable of fulfilling all of the needs at a relatively high level.

3g - Required traits for TCT models

Use of the theory requires setting up a model or simulation that will permit actual calculations and analysis. Regardless of the methods and tools used, each implementation will need to meet the following technical requirements:

a) Must be capable of representing or simulating CAPACITY, UTILIZATION, and annual growth.
b) Must enable users to find and quantify optimal activity level points for multiple traffic levels and/or road types.

c) Must be able to support calculation of the net savings that can be attained from making a capital improvement.
d) Must be able to model changes in utilization and growth rates induced by projects.
e) Should permit identification of individual road segments that meet project selection criteria.
f) Should be easy to update and open to progressive refinement.

3h - Summary and observations

Development of the theory outlined in this section took approximately six years. The author believes that, in its present form, it can be used to frame most transportation issues in a standardized way. It is expressly open to revision and refinement as new ideas and insights arise. The overall form and structure make the concept amenable to computerized implementation. The most challenging part of applying it will be that of obtaining reliable cost data to place in the model(s).

Section 3 References

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FHWA. (1995). Our Nation's Highways – 1994 U.S. Dept. of Transportation, Washington. D.C.

Iowa Department of Transportation. (1993). Annual vehicle miles of travel tabulation. Ames, Iowa.

Chapter 4

TCT IMPLEMENTATION

4. TCT Implementation

To permit evaluation of a concept's ideas, an appropriate model must be set up to serve as the framework for quantitative analysis. This section reviews the options considered for TCT implementation, identifies the one chosen for use, and provides background reasoning. Then the selected method is explored in depth and evaluated against the criteria set forth in Chapters 2 and 3.

4a – Requirements

Several issues attended the determination of how to model and utilize the TCT theory.

a) The model needed to fulfill the criteria identified in Chapter 2 and faithfully represent the theory advanced in Chapter 3.
b) The model had to be capable of capturing both the physical and economic dimensions of the overall system and their interconnections.
c) It also needed to permit viewing the physical side of the system in two ways: as an entity composed of discrete parts and as a unified whole. (Scalability)
d) It would have to permit stratifying and analyzing the road based transportation system's levels of service, (LOS), and traffic levels in some discrete format.

4b – Modeling options

Methods considered for TCT implementation included:

a) Developing a custom analysis package using formulas and matrices to model the theory. This would provide precise representation and best analysis – but would be too expensive and hard to update.
b) A system simulation package would provide dynamic insight into the interactions of price, capacity, utilization, and cost. But it would also be expensive and tracing results back to inputs would be hard.
c) Geographic Information Systems could represent TCT and UCT data in the most intuitive format for citizens but would be weak in the area of cost analysis.
d) Relational databases would be excellent for modeling a system as a composite of unique parts but would fall short in supporting cost analysis.
e) Spreadsheets, on the other hand, while very good at representing the whole and facilitating cost analysis, wouldn't be a good tool for identifying and selecting individual road segments belonging to a type and traffic category.

After evaluating the options enumerated above, the author concluded that a combination method using both a database and a spreadsheet would work best. This approach appeared most able to represent the physical system both as a collection of parts and as a unified whole – and capable of efficient cost data processing. The database component also would support future use of GIS technologies for displaying inputs or results. Accordingly, the combination method was chosen for final development.

4c – Details of the Database / Spreadsheet model

The database / spreadsheet model starts by using road segments as the foundation for representing the RBTS and organizing the data that defines the system. They provide a good base upon which to model the system because all other components either operate upon them or are linked with them.

4c-1 Road network database

For the database to properly model the entire RBTS, the data fields attached to each segment need to define both capacity and utilization, in addition to roadway physical parameters. The following table illustrates what items are necessary to meet this objective:

Table 4.1 : Data fields needed to define the RBTS based on road/highway segments

1. Identity & classification fields	**2. Physical state fields**	**3. Level of service fields**	**4. Level of use fields**
System class	Cross-section geometry	Percent of year open for unrestricted use	Current AADT
Jurisdiction type & ID	Profile	Accident rate	AADT growth rate
Road & Segment ID	Surfacing	Average speed of travel	Percent trucks
Functional Classification	Bridge lengths and widths	Amount of destination parking adjoining	Percent agricultural vehicles
	Condition & Depreciation	**Road type, (LOS), designation**	**Traffic range, (TR) designation**

(Other fields may be added if those above fall short of fully defining all dimensions of the RBTS.)

The items of Table 4.1 effectively capture the size, state, capacity, and activity of the RBTS to be analyzed. The more completely they can be populated with data, the greater the model's ability to accurately represent the overall system will be.

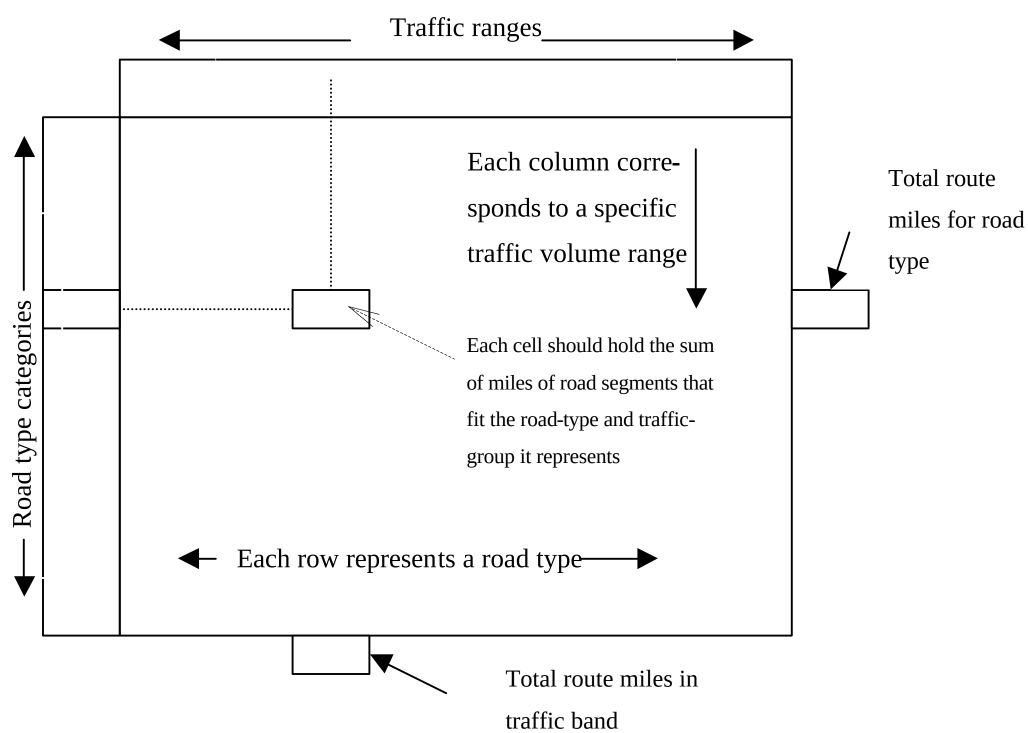
4c-2 RBTS summary spreadsheet

While the RBTS can be represented via a database of road segments having the attributes noted in the previous section, the database isn't a good format for analyzing the system as a whole. That requires a summary format that can be laid out on a single sheet of paper. A spreadsheet tabulation can best serve that need – by consolidating the data into a format that can be linked with matching cost data.

4c-1.1 System-as-whole representation

The form of spreadsheet chosen for use in this project is shown in Figure 4-1. It represents the system as a two dimensional array. (The individual records of the database must be sorted and summed into the worksheet's cells – as described below – before spreadsheet analysis can occur.)

Figure 4-1 – RBTS road network & utilization worksheet format



The details of this form of system representation are as follows:

a) Each row must correspond to a unique level of service, such as "Earth surfaced", "Gravel", Seal Coat", or "Paved", with the labels shown in the left-hand column. There must be enough rows to represent all road types but not so many as to overly disperse the data.

b) Each column in the main body of the worksheet should correspond to a unique traffic volume range, like "201 to 300 vehicles per day". The header rows of these columns need to hold the minimum, maximum, and average VPD figures for each traffic band. There must be enough columns to keep the ranges reasonably narrow yet model the full range of traffic from zero to the system maximum.
c) Each cell in the worksheet, being formed by the intersection of a row and a column, represents a particular combination of road-type and traffic-level. By storing the total miles of roadway having each LOS / Traffic level characteristic in the matching cells, the spreadsheet can portray both network size and system activity level in one page.
d) The rows can be summed to the right to determine total miles of each level of service.
e) The columns can be summed down to determine total miles for each traffic level.

In addition to statically modeling the system, the spreadsheet format can also simulate changes that occur as time passes:

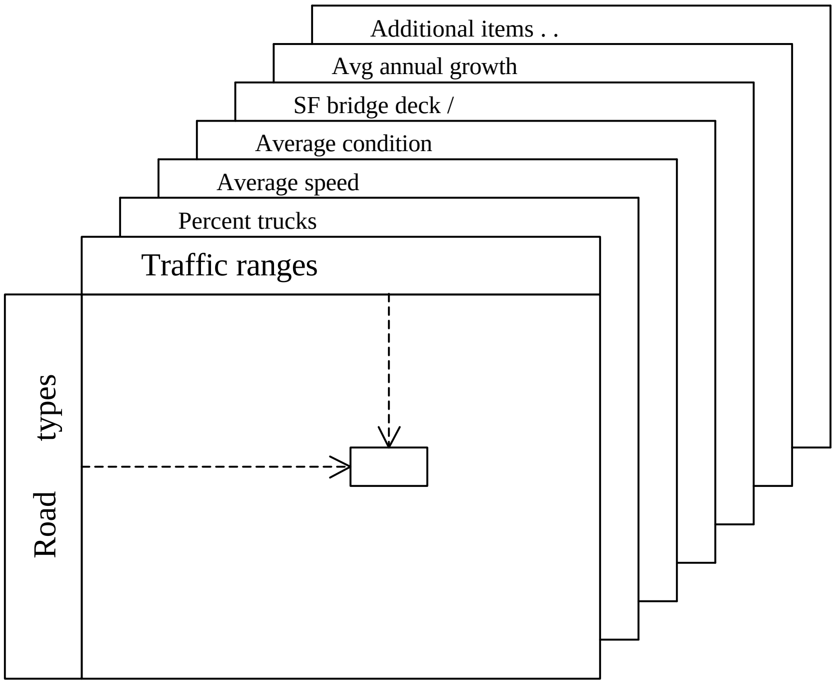
a) Traffic growth, (increased system utilization), can be represented by shifting mileage to the right – from a lower traffic band to a higher one.
b) Road improvements, (capacity & quality enhancements), can be modeled by moving mileage up – from a lower design service level to a higher one – and then shifting part of it to the right to account for the increment in utilization induced by reduced time & distance prices.
c) Construction of new route miles, (capacity expansion), can be modeled by adding in new mileage in the cell that best represents the new segment's type and startup traffic level.
d) The annual growth of system activity caused by overall gains in road, vehicle, and driver capacities can be handled by applying growth factors to all cells.

4c-1.2 Inclusion of auxiliary data

Additional data, regarding things like bridges, truck volumes, and average speed of travel, are needed to fully define RBTS status and behavior. Such items are also needed for computing unit costs of transportation for each level of service and traffic volume combination. So matching auxiliary worksheets must supplement the base tabulation, linked to it in a three dimensional arrangement. The auxiliary sheet data values modify or amplify the basic road type and traffic range data.

Figure 4-2 illustrates this arrangement:

Figure 4-2 – Supplementary system definition worksheets



If desired, each parameter could be broken down in more detail within each auxiliary page by employing sub-ranges that sum into the top, totals range. For example, to more precisely represent road network condition, the designated page could use five sub-ranges corresponding to Poor, Fair, OK, Good, and Excellent ratings. The miles of roadway fitting a particular type & traffic combination could then be distributed into the condition cells. Then, using formulas, the worksheet could determine the average condition for all road type – traffic level combinations.

(Bridges can be handled in either of two ways. They can be treated as special, high cost road types, or their count and size can be averaged across the road network. The former method will work best when dealing with specific project studies. The latter provides the most convenient way to represent structures when conducting system level analysis.)

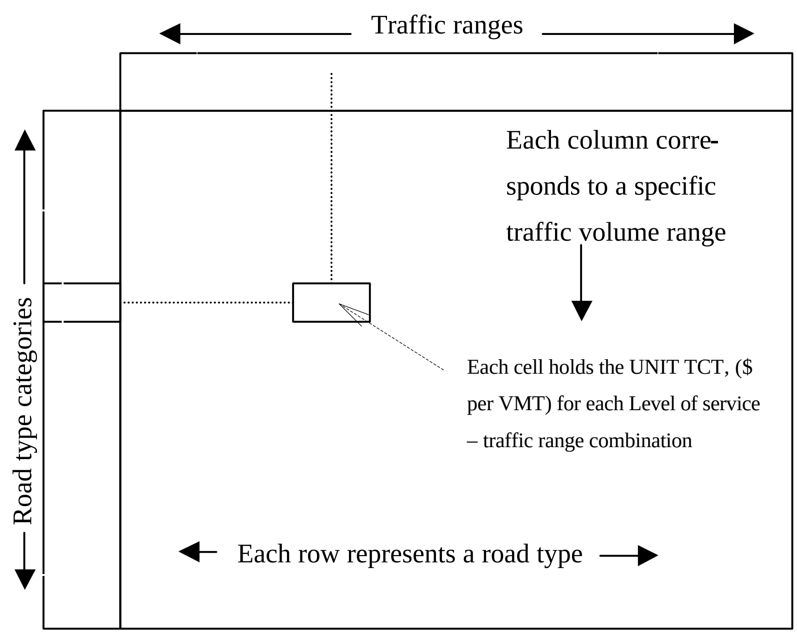
4c-3 Unit TCT determination

Trail and error work revealed that the best way to conduct TCT analysis is to determine and find differences between unit cost of transportation, *UCT*, values expressed as Dollars per vehicle mile of travel, *$/VMT*. This section describes how the spreadsheet model enables this to be done:

4c-3.1 Basic concept and layout

The UCT sheet should match the level of service – traffic range worksheet's format cell for cell. However, in lieu of mileage, each cell of the cost table should hold the unit cost of travel upon the designated road type at the indicated traffic level. This can be computed by summing the fixed, distance, and time unit costs for the categories identified in Section 3e-3.1: Roads, Vehicles, Paid (human resource) time, Accidents, Business/Economic factors, and Social/Environmental items. Figure 4-3 shows the layout of the Unit TCT summary sheet.

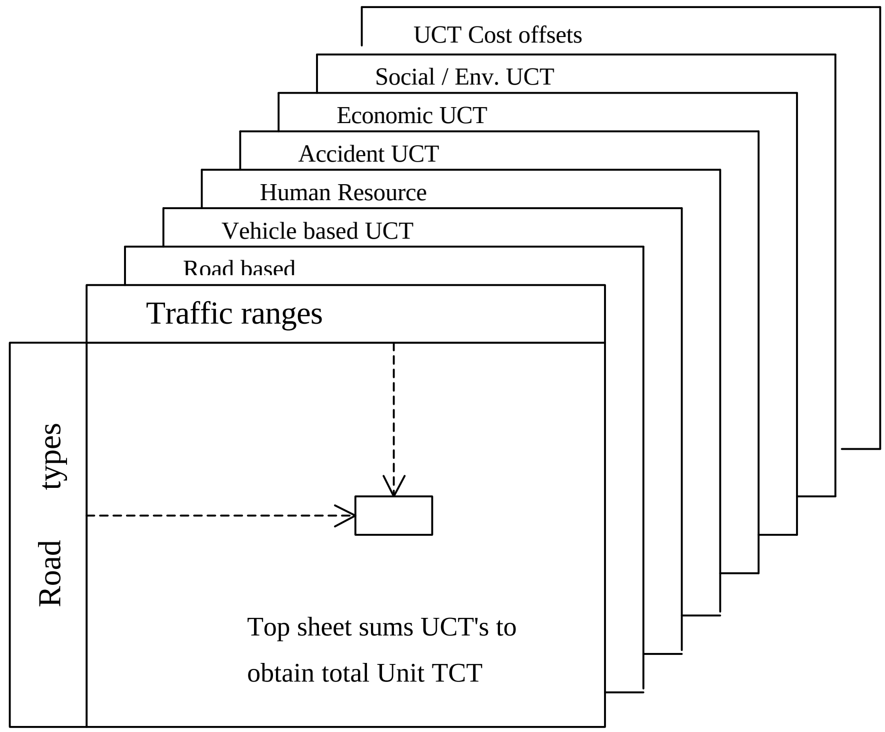
Figure 4-3 -- Unit TCT worksheet format



4c-3.2 Cost category worksheets

An objective, detailed, and well-organized way to determine Unit TCT values is essential. The method must not bias the outcome, every known system cost must be included, and the format of the calculations must be open to inspection by others. Figure 4-4 illustrates an arrangement of auxiliary cost category sheets chosen to meet those objectives:

Figure 4-4 – UNIT TCT categories

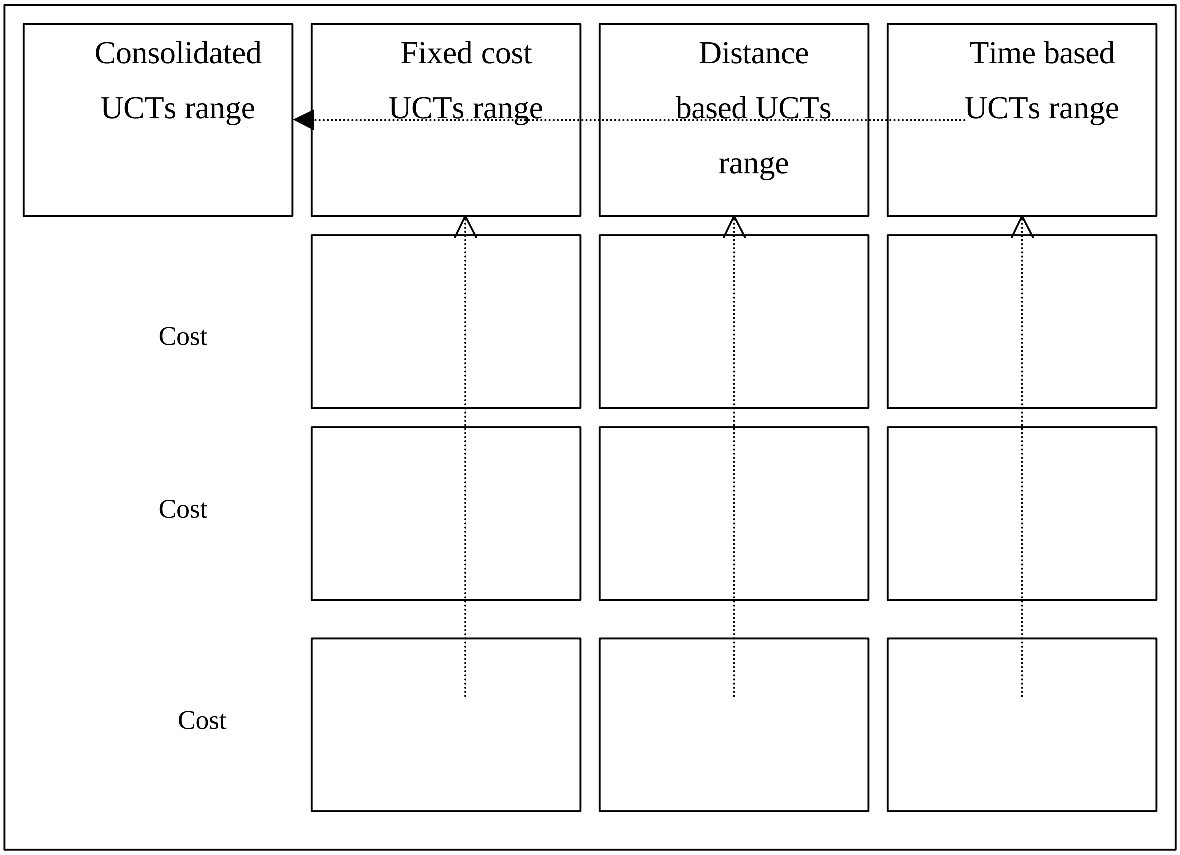


Each sub-category sheet must match the main sheet. The sub-costs computed within each can then be summed into the top sheet's cells to compute the final unit cost, or total UCT.

4c-3.3 Internal layout of cost worksheets

For ease of understanding and openness each of the Unit TCT sub-category worksheets needs to employ a standardized layout. As shown is Figure 4-5, this can be accomplished by structuring each one as follows: a) the totals area in the upper left corner, b) the fixed, distance, and time costs summaries across the top, and c) subordinate fixed/distance/time cost ranges for each identified cost item.

Figure 4-5 – Internal layout for individual UCT worksheets

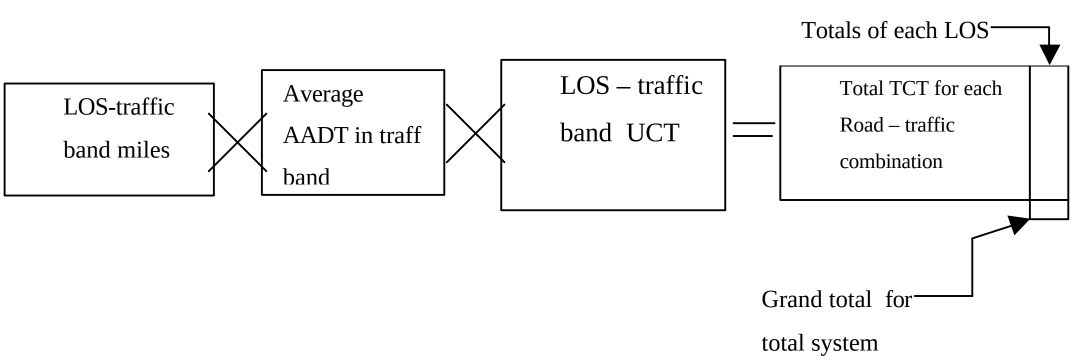


The computed TCT vales are consolidated by summing them upwards into the top ranges, and then summing those to the left. This approach may require a large number of cost sub-ranges but is relatively simple to implement and enables easy inspection of both data and calculations.

4c-4 Calculation of TCT

Once the Unit TCT values have been determined, the overall system TCT can be computed, as indicated in Figure 4-6:

Figure 4-6 – TCT computation diagram



The calculation proceeds as follows:

a) Compute total annual VMT for each base sheet cell:

$$VMT_{annual} = Miles_{\text{In LOS \& Traffic band combination}} \times VPD_{avg} \times 365$$

b) Multiply the value from a) times the associated UCT from the cost sheet.

c) Store the result in a TCT consolidation sheet.

d) When cell by cell calculations are complete, sum each row in the consolidation sheet and store the totals in its right hand column.

e) Sum that column to obtain the system total TCT.

4d - Basic model operation and use

This section outlines how to apply the general modeling concepts in specific investigations.

4d-2 Initial data collection and storage

The first required action is to collect relevant data, store it in an appropriate format, stratify it, and determine maximums and minimums. This information can come from the investigator's own sources or obtained from an agency like the Iowa DOT. However acquired, the data should be placed in a database and readied for processing.

4d-2 Development of the TCT spreadsheet

To enable study of an RBTS system as a whole, the database records must be consolidated into the summary spreadsheet format described in Section 4c-2. This involves deciding road and traffic stratifications, setting up a worksheet format, and pulling the database information into the cells..

4d-2.1 Select and set road types

After examination of the range of road segment characteristics found in the data, the investigator must designate a finite number of unique road types, or “levels of service”, LOS. This will determine the number of rows needed within the spreadsheet. Then a scheme must be devised for associating each database record with a LOS. The type designations should be developed from physical characteristics and avoid use of existing labels, like functional classification, as these items may contain pre-judgments that could bias the outcome.

4d-2.2 Select and set traffic bands.

The second step in worksheet setup is to determine the number and ranges of the traffic bands. These designations must encompass all traffic levels found within the system – from zero to the maximum. The breakdown of the overall range into discrete bands should be done in a way that minimizes introduction of subjective bias and accommodates any limitations within the data. The number of bands so determined sets the number of columns needed in the worksheet. Similar to the case of road types, a matching scheme must be devised to associate each database record with a specific traffic count range.

(SPECIAL NOTE: The use of traffic bands assumes that traffic volumes are evenly distributed across the range of possible values within each traffic band. When this is so, the band's average traffic level, (half the sum of the maximum and minimum values), reasonably corresponds to the mileage-weighted average that can be computed from the actual road segments involved. But it is possible that the two averages will not be equal in some circumstances. This possibility can be minimized by limiting the number of road types and traffic bands – which will maximize the number of segments per cell.)

4d-2.3 Set up spreadsheet and process data into it

After a determination of road types and traffic ranges has been made, the basic and auxiliary spreadsheets should be set up. When they are complete, a pivot table query may be run on the database to compute the number of miles of roadway that fit each type-traffic category. After the results have been stored in the base worksheet, auxiliary system data may be added into the supplemental sheets.

4d-2.4 Develop cost figures

Obtain all necessary cost figures and reduce them to UCT form by use of appropriate formulas, taking care to avoid double-counting any items. Summing the source cost classes into the final UCT sheet to readies the model for use.

4d-2.5 Determine least TCT points

Within each traffic band, identify and highlight the row having the least UCT. This locates the economically optimal level of service for each traffic band. These cells will likely form a diagonal band across the face of the worksheet. Then highlight the corresponding cells in the system mileage worksheet. *(Note: Within this report, the term "Level-of-Service" is the combination of a road type's physical characteristics plus the level of operations and maintenance service it typically receives. Do not confuse this with the concept of Level of*

Service used by traffic engineers to classify traffic density - capacity utilization on major routes into A, B, C, D, E, and F categories, where A stands for free-flowing and F stands for unstable, stop-and-go situations.)

4d-2.6 Use the model for analysis and decision support

A variety of observations becomes possible once the least UCT points have been identified for each traffic range. These apply at the instant in time represented by the model's data. The following list illustrates the types of information that might be drawn from inspection of the completed model:

1. Roads that fall short of the level of service provided by the optimal type of their traffic band could be classified as under-improved. Upgrading them would reduce the system's TCT.
2. The greater the difference between a particular road type's actual UCT and that of the optimum, the greater the justification for improving it.
3. The net annual savings per mile to be achieved can be estimated by multiplying the [UCT difference] X [the average traffic count] X [365].
4. Different improvement options can be compared by dividing their cost reduction potential by their estimated per mile price.
5. Roads built to a higher standard than the optimum for their band should be classified as over-built. Their increased fixed cost probably exceeds the distance and time cost savings afforded by the extra investment.
6. An economically optimum system would have all of its mileage concentrated into the least Unit TCT cells of the various traffic ranges.
7. The compactness or dispersion of mileage within the worksheet provides an indication of how well the road agency has been able to meet the public's needs.
8. The worksheet enables comparisons between different levels of improvement within a single traffic range.
9. It also permits comparing the merits of making many minor improvements with that of just making a few high cost improvements.
10. By referring back to the road cost sub-sheet, it's possible to calculate the funding needed to maintain the road network – both as built and as it would be if all roads fell into the optimal type-traffic determinations.
11. The model's sensitivity to economic and physical changes can be explored by varying appropriate physical and cost factors.

12. The relative magnitudes of the contributing cost items can be compared to determine the best methods for future cost reduction.
13. A unit price versus activity level table could be derived from the cost data for use in studying transportation demand issues.
14. If analysis shows that road segments of a particular type and traffic combination ought to be improved, individual sections fitting that criteria can be reported from the database.

As the depth of the list suggests, point-in-time TCT analysis should be able to help evaluate and decide many issues: road network adequacy, project selection, prioritization, determination of proper funding levels, and price vs. demand analysis.

4d-3 Future outcome projections and analysis

While point-in-time investigations are quite useful, real system planning and strategy development require studying how things evolve, change, and interact with the passage of time. This section outlines how TCT methods could serve this need.

4d-3.1 Relationship of time point and time interval analysis

Point-in-time analysis studies how things are and helps one decide what immediate actions ought to be taken. Time interval analysis helps with the development and evaluation of long term strategies. In general, elapsed time analysis can be conducted by updating and reevaluating the point in time model at regular intervals. It usually involves testing how particular set of policies, applied repetitively, will turn out.

4d-3.2 Methods

This section outlines the basic sequence of work required to perform elapsed time analysis:

1. Set up and analyze the initial point-in-time model and decide what actions should be taken in the time period about to commence: choose projects, set funding levels, adjust growth rates, and update costs.
2. Adjust the database to reflect the changes caused by the chosen actions.
   - Change road type designations for improved road segments.
   - Add records to the database to model the construction of new roads.
   - Adjust the traffic levels and growth rates for segments impacted by changes on others.
3. Age the model's gradual trend parameters.
   - Apply traffic growth factors to all segments in the database.

- If the data contains condition rating items, age them appropriately.
- Adjust cost factors as needed.
- Adjust growth rate / change rate factors as the situation indicates. (These changes won't impact the model until another cycle elapses.)

4. Re-evaluate the system through use of the updated point-in-time model.
   - Redo the point-in-time analysis procedure and make a new set of action determinations.
5. Repeat steps 2, 3, and 4 as many times as needed.
6. To evaluate alternate strategies, start from two identical initial models and update them independently.

4d-3.3 Applications of time interval study

TCT time interval analysis can be to investigate the following issues:

1. How well might a particular maintenance strategy work over time.
2. How might things turn out if funding stays the same, gets reduced, or rises?
3. Where will traffic growth create a need for improvements in the future?
4. What long-term trends may occur and how would they impact the system?

4e – Model suitability

As was done with the theory of Chapter 3, this section evaluates the database-spreadsheet TCT implementation idea from several perspectives.

4e-1Fulfillment of criteria

This sub-section evaluates the ability of the model to meet the various goals and requirements articulated in previous chapters of this report.

4e-1.1 Chapter 2 needs

In Chapter 3, the theory was evaluated for its ability to meet the method improvement goals identified in Chapter 2. The following table performs the same analysis for the proposed model:

Table 4-2 Evaluation of TCT database-spreadsheet combination to meet Chapter 2 needs.

No	Description	Estimated suitability of theory. (From Chapter 3)	Estimated suitability of proposed method
1	Need to base analysis and decision making on economics	95%	95%
2	Need to develope broad, total system perspective.	95%	95%
3	Need to reduce or eliminate built in biases or pre-dispositions.	90%	90%
4	Need tools that assist in identifying optimal solutions.	90%	85%
5	Need tools that enable evaluation of tradeoffs between two design level options for a particular traffic level.	90%	85%
6	Need a process that is open to inspection by anyone interested.	85%	75%
7.	Need a process that non-professionals can understand.	75%	65%
8.	Need a scalable method of analysis.	75%	70%

4e-1.2 Chapter 3 technical criteria

Section 3g identified a number of traits that a TCT implementation method should possess. The following table evaluates the to degree to which these items have been met.

Table 4-3 Evaluation of TCT database-spreadsheet combination to meet Chapter 3 criteria.

No	Description	Estimated suitability of proposed method
1	Must be capable of representing Capacity, Utilization, and Annual growth.	65%
2	Must be able to handle multiple traffic levels and road types.	95%
3	Must be able to compute net savings caused by improvements	95%
4	Must be able to model projects' impacts on utilization	85%
5	Should permit identification of individual road segments of a type selected for improvement.	95%
6	Should be easy to update	90%
7	Should be open to progressive refinement	90%

4e-2 Feasibility and usability

The database-spreadsheet model appears theoretically and practically feasible. Usability should be acceptable, but must be tested and proved with actual data before a final judgement may be rendered.

4e-3 Assumptions & limitations

The implementation methods will likely implement the TCT theory in a valid way. Although no major concerns exist in this regard, several accuracy affecting factors should be understood:

1. Traffic band averages VPD figures may not exactly match the mileage weight VPD average that would be calculated from the source road segments. (This proved true with the data used in Chapter 7 of this project).
2. Associating segments with a finite number of road types, while necessary for analysis, slightly reduces the level of precision attainable.
3. The model does not directly model the interaction of transportation demand with transportation pricing. It assumes that in normal circumstances that price and demand are very stable and that their joint action can be represented by annual percentage growth factors.

Chapter 5

TCT COST ELEMENTS

5. TCT Cost elements

Chapter 4 outlined the implementation model chosen for testing the TCT concepts. This chapter presents detailed information on identifying cost items and allocating them within the model.

5a – Cost type review

Chapter 3 identified three fundamental cost types: fixed, travel distance based, and travel time based. This section further defines these items and discusses factors that need to be considered in developing certain individual cost elements

5a-1 FIXED COSTS

Fixed costs of transportation have the following characteristics:

1. The annual, per mile, total is tied to road type and is the same for all segments of a particular type -- regardless of traffic level.
2. Because the total is independent of traffic level, the unit cost per mile of travel decreases inversely as utilization increases.
3. These costs generally represent the capital and operating expenses of providing pathways for vehicles to operate upon – but also include things like terminals, parking, and the legal/financial institutions required for the system to work.

5a-2 TRAVEL DISTANCE COSTS

Travel distance based costs mostly result from the expenses of vehicle operation:

1. The per-mile amount is nearly constant and isn't affected by either road type or speed of travel.
2. Because the cost factors for cars, trucks, semis, farm vehicles, etc., differ, an average cost per mile must be figured for any given traffic stream.

5a-3 TRAVEL TIME COSTS

Travel time costs are associated mostly with the drivers, passengers, and freight in transit. These cost items exhibit the following traits:

1. The rate per hour of travel is essentially constant and independent of road or vehicle choice.
2. The per-mile magnitude of this cost varies inversely with the speed of travel.

It is important to differentiate between travel time costs and calendar time costs. Travel time expenses accrue only for hours elapsing while a trip is in progress. Calendar time costs, however, accrue continuously, 24 hours per day – whether one is in motion or not. The latter item will often need to be entered into TCT as a fixed or distance based cost element.

The choice is made as follows:

1. If a cost varies directly with speed of travel, count it as a travel time expense.
2. If a cost remains the same regardless of route or speed of travel, treat it as a distance based cost.
3. If a cost varies by type of roadway and not with traffic, count it as a fixed cost.

5b – Special cost capture issues

The cost figures used within a TCT model need to be as accurate and complete as possible. To that end, there are a number of precautions that should be observed when collecting and processing cost data:

1. Separate CHARGES from COSTS and use only the latter. For example: the charge for a gallon of gasoline may be $0.95. But the government's charge for the road system, the gas tax, must be subtracted out to determine the real economic cost of the fuel itself.
2. Avoid double counting. Watch for situations where a charge may contain a cost element already included elsewhere in the model.
3. Carefully consider whether to allocate a cost item as fixed, distance based, or travel time based.
4. Be alert for hybrid situations. Some cost elements will prove difficult to assign to a single cost type. (For example: should parking costs be considered road or vehicle related?)

5c – Cost Source Categories

The following sections enumerate cost sources for use in TCT analysis, noting:

a) Items that should be included
b) Sources and methods for procuring the necessary data.
c) How to compute the Unit cost of transportation, UCT, for various items.

The assignment of each element as Fixed, Distance based, or Time of travel based is indicated in the right hand columns of each tabulation.

5c-1 Road network based costs

The road network component of the RBTS is made up of the roads themselves, the agencies that manage them, the contractors that build them, the laws and codes that govern them, and associated private roads, etc.

The most accurate way to determine the costs produced by this sub-system is to extract data from road agency budgets and construction reports. Most expenses within this sector flow into charges paid by those agencies. However, a few cost items fall outside such charges and must be handled separately.

Separate cost determinations must be done for each road type included in the TCT model.

Table 5.1 Road network cost elements **F=Fixed / D=Distance / T=Time based**

No.	Element	Remarks	Cost types		
100	Capital Investment Expense		F	D	T
101	Cost of capital	Obtain or determine depreciated capital investment in a road type. Then compute cost of capital by multiplying times an appropriate rate of return. Divide by VMT to obtain unit cost.	X		
102	Annual Depreciation	Multiply depreciation factor times original capital value, then divide by VMT	X		
110	Direct expenses				
111	Administration	Apportion admin. expenses to each road type then divide by total VMT in all traffic bands.	X		
112	Engineering	Same as administration – but don't include engineering that becomes part of projects.	X		
113	Operations	Include costs of operation: electricity, snow removal, etc.	X		
114	Maintenance	Items of work intended to prevent depreciation of the assets. Patching, blading, mowing, ditch cleaning, brush removal, etc.	X		

115	Repairs	Items that replenish capital value without actually rebuilding or improving the roads: new rock, minor patching, small culvert replacements, etc. Include costs here only if they are not accounted for by depreciation. (Item 102)	X		
120	Framework expenses				
121	Road statues & codes	Allocate costs of Code of Iowa, Iowa Admin. Code, and other rule making	X		
122	Built up case law	Estimate and include value of case law not already paid for with road monies.	X		
123	Road oriented research	Allocate cost of road research to the road types that benefit therefrom.	X		
130	Other costs				
131	Destination parking	This is a difficult item to allocate. For this project it was decided to place 1/3 with abutting roads	X		
		and apply the remainder as a vehicle based travel distance cost.		X	
132	Linked private roads	Include the annual costs of private roadways immediately connected with a public road type.	X		

5c-2 Vehicle based costs

The vehicle component of the RBTS includes cars, trucks, motorcycles, trailers, filling stations, car dealers, a legal-administrative-financial framework, part stores, car washes, garages and other base-of-operations parking, towing services, junk yards, advertising, vehicle related law enforcement, research operations, and more.

Costs of this sector must be compiled from a variety of sources. Although many costs flow into charges paid by vehicle owners, a significant number do not. After the cost data has been acquired, the per-mile amount must be computed for each class of vehicle within the traffic stream. Then, an average, or composite, per mile rate should be figured for each road type and traffic range combination in the system – based on the percent of each type of vehicle typical in that setting.

Table 5.2 Vehicle associated cost elements **F=Fixed / D=Distance / T=Time based**

No.	Element	Remarks	Cost types		
200	Capital Investment Expense		F	D	T
201	Cost of capital	Compute cost of depreciated capital investment in each major vehicle type. Then divide by average annual mileage.		X	
202	Depreciation	Determine average lifetime miles for each vehicle type, then divide into annual depreciation based on new value.		X	
210	Direct expenses				
211	Operations	Gas, oil, consumables		X	
212	Maint. and repair	Include charges for washing, repairs, tires, windshield replacement. Do not include accident repair bills.		X	
213	Accessory purchases	Amounts spent on vehicle accessories, books, magazines, etc.		X	
214	Towing and road svc.	Average the annual amount spent on wrecker services across all vehicles.		X	
215	Final disposal	Figure a cost to dispose of all used tires and the vehicle itself.		X	

220	Framework expenses				
221	Legal	Figure annual cost of capital invested in motor vehicle codes		X	
222	Financial	Figure annual cost of auto finance industry administration		X	
223	Administrative	Figure annual cost of government executive branch departments that provide motor vehicle registration and licensing		X	
224	Law Enforcement	Figure annual cost of vehicle related work on things like auto theft, car jackings, etc.		X	
225	Research	Annual amounts expended on vehicle research.		X	
230	Other costs				
231	Base of operations	Include base of operations costs in vehicle costs. Include driveway and garage costs with cars, terminal storage and parking for trucks.		X	
232	Media and advertising	Include amounts spent by media to report on cars plus the value of all vehicle advertising not captured in the charge paid by the buyer.		X	

5c-3 Human resource costs

The human resource component of the road based transportation system includes drivers, passengers, a legal-administrative framework, support facilities, etc. Cost data for this sector must be computed for each class of driver/passenger and then averaged to reflect the actual composition of the traffic stream.

Human resource costs are mostly figured on a per-hour-of-travel basis and are easy to compute. The challenge lies in deciding which person-hours should be included in the calculations. Since TCT intends to count only true economic cost, it must differentiate between work time and personal time. The former is considered to be an economic resource while unpaid personnel time is treated as being of zero cost. This is decided in the following manner:

1. If the time consumed by travel would have otherwise been spent in some other productive capacity and the driver/passenger was being paid a wage while traveling, treat it as a cost.
2. But if the traveler(s) were only engaged in personal, non-production activities and was not receiving any compensation while on the road, no economic resource should be considered lost or consumed.

Based upon this criteria, a truck driver's time should be included as a human resource cost of transportation. But time spent driving from home to the golf course or traveling to visit a friend should not. Time consumed driving from the office to a project site would count as a cost, while home to work commute time would not – unless it could be said that the commuter would work more hours per day if freed of the trip time.

Although the TCT approach treats personal activity time as having zero cost, it is not asserting that those hours have no value to the people involved. It's just saying that no economic production is lost when it takes someone ten extra minutes to drive to a movie – but there is a measurable monetary cost when a paid employee spends an hour in a vehicle. Nor does TCT assert that the perceived value of personal activity time isn't important. Since personal trips are a large percentage of the total, driver and passenger time-price perceptions about such travel have a significant role in establishing the overall level of activity within the system.

TCT does not attempt to determine or compare driver/passenger benefits with costs. It presumes that the magnitude and distribution of traffic upon the road network is a collective reflection of the myriad of price versus value decisions made by individual drivers every day. It then looks at how to minimize the overall cost of that market force determined activity level.

Table 5.3 Driver / Passenger associated cost elements F=Fixed / D=Distance / T=Time based					
No.	**Element**	**Remarks**	**Cost types**		
300	Capital Investment Expense		F	D	T
310	Direct expenses				
311	Wages & Benefits	Determine and average wages and benefits paid to people while they are driving or riding in a vehicle.			X
312	Labor administration	Add in costs of payroll, workers compensation admin, etc.			X
313	Overhead, training, equipment, and safety	Include amounts expended to manage, inform, train, equip, and protect personnel while they are traveling in vehicles.			X
320	Framework expenses				
321	Legal	Annualized value of rules of the road and driver licensure codes.			X
322	Administrative	Annual cost for government to issue, track, and manage drivers' licenses.			X
323	Traff. Law enforcement	Amounts expended to enforce traffic laws in the field and send officers to court			X
324	Traffic court operation	Cost of operating traffic courts			
330	Other costs				
331	Drivers' education	Annual amounts spent to educate new drivers and retrain old ones			X
332	Safe driving advocacy	Amounts spent by traffic safety and anti drunk driving organizations.			X

5c- 4 Accident costs

Accident costs include property losses, the expense of medical treatment for injuries, the loss of productive time, and the administrative expenses of the insurance industry from processing claims. Accident frequency and severity vary both with road type and traffic level, so a unique cost per VMT factor will need to be set for each road type and traffic level combination.

Table 5.4 Accident cost elements			**F=Fixed / D=Distance / T=Time based**		
No.	**Element**	**Remarks**	**Cost types**		
400	Capital Investment Expense		F	D	T
410	Direct expenses				
411	Incident response	Costs of accident response: towing, law enforcement investigation, medical and EMT services, fire dept. services.	X		
412	Vehicle damage	Amount of damage sustained by all vehicles	X		
413	Road asset damage	Damages to bridges, guardrails, signs, etc.	X		
414	Property damage	Damages to private property: fences, buildings, livestock, etc.	X		
415	Cargo losses	Damages to cargo carried by vehicles	X		
416	Medical Care	Cost of post incident care, treatment, and rehabilitation	X		
417	Lost production	Value of productive time lost while accident victims recover. Value of EMT volunteer's time taken off from work to assist at an accident.	X		
418	Loss of life	Economic cost to society for the loss of an individual	X		
419	Post incident cleanup	Environmental cleanups necessitated by spills.	X		
420	Framework expenses				
430	Other costs				

5c-5 Economic costs

This heading covers a diverse sub-section of the RBTS: items that support and assist general operation of the system. This includes command and control activities, cargo costs, and en-route support facilities.

Table 5.5 Economic cost elements **F=Fixed / D=Distance / T=Time based**

No.	Element	Remarks	Cost types		
500	Vehicle use support facilities		F	D	T
501	Freight terminals	Associate the costs of docks, transfer warehouses, and other load/unload facilities with trucks		X	
502	Drive up service installations	Associate the costs of drive up services from banks, restaurants, grocery stores, drug stores with cars		X	
503	Logistics centers	Associate costs of transportation logistic management centers with trucks		X	
510	Driver / passenger support facilities				
511	En-route food, dining, lodging	If facilities found along a route would not have been built anywhere else in the area, count their costs as part of the road type's fixed costs.	X		
512	Communications services	Charge the cost of wireless communications used while traveling against human resource time.			X
520	Information and guidance				
521	Outdoor signs and advertising	Charge both the costs of road travel related signs and government's cost of regulating them	X		
522	Motor clubs, traffic info services, maps	Apply amounts expended for travel information and services as a distance based cost.		X	
523	Media	Allocate the value of non-trade media coverage of driving, roads, and vehicles		X	
530	Cargo related costs				
531	Cost of capital	Allocate cost of capital-in-transit by figuring average value vs. minutes of occupancy per road segment mile			X

		per year.			
532	Depreciation	Allocate en-route depreciation the same as for #531			X
533	Loss and breakage	Average total breakage and loss expenses across the miles driven by all trucks.		X	

5c-6 Social / Environmental costs

Social and environmental costs arise when transportation activity causes losses – or the need for extra expenditures.

Table 5.6 Social and Environmental cost elements **F=Fixed / D=Distance / T=Time based**					
No.	**Element**	**Remarks**	**Cost types**		
600	Social costs		F	D	T
601	Cost of restoring non-RBTS links	Include costs of pedestrian and bike crossings and/or stock passes.	X		
602	Induced extra cost of future utility expansion	Estimate the induced future cost to extend utilities or repair old lines due to the presence of a road type.	X		
603	Business disruptions	Estimate the non reimbursed losses born by businesses when impacted by road construction. Things like cost of moving goods from old site to new one, cost of extra advertising required to rebuild business volume, etc.	X		
610	Environmental costs				
611	Fugitive dust	Use the amount spent each year, per mile of road, to apply dust control as a measure of this cost.	X		
612	NO/VOC air pollution	Estimate this cost from FHWA guidelines		X	
613	Noise pollution	Use the estimated cost of constructing sufficient sound barriers to meet all noise limits as a measure of this item.	X		
614	Visual blight	Figure annual cost of capital required to full correct and eliminate visual blight	X		
615	Water pollution	Include this cost when known. A significant share is recovered via the underground storage tank cleanup fees incorporated into the charges paid for fuel.		X	
616	Other Resources	Wetlands, Flood plains, archaeological sites, and historical elements	X		

5c-7 Cost offsets

Cost offsets have been included in TCT to reflect the fact that, in some cases, the existence of the RBTS makes it possible for society and business to reduce costs in other parts of the economy. Such savings are difficult to evaluate, so they should be determined with great care. For this project, they have been included only when a road type appeared to directly impact the cost of operations or value of assets within the private sector immediately abutting the road.

Table 5.7 Transportation related cost offsets **F=Fixed / D=Distance / T=Time based**

No.	**Element**	**Remarks**	**Cost types**		
700	Capital Investment Offset		F	D	T
701	Annualized value of alternate capital expense avoided	If the presence of a road, coupled with use of vehicles has permitted the private sector to decrease or avoid capital investments, the cost savings should be used to reduce the net capital cost of the road itself.	X		
710	Direct expense offsets				
711	Operating expenses avoided.	If the presence of a road, coupled with use of vehicles, enables the private sector to reduce or avoid operations and maintenance expenses of other assets, the savings should be used to reduce the net operating costs of the road.	X		
712	Value of free utility accommodation	Deduct the market value of utility accommodations from the cost of the roads that host them.	X		
720	Framework expense offsets				
721	RBTS induced land value gains	If improvement of a road facility induces an increase in the value of adjacent land, part of the induced gain should be subtracted from the road's capitalization cost.	X		
722	Watershed and stream stabilization	If the presence of road network drainage structures prevents loss of land and saves non-road assets from harm, a credit should be applied to reduce the net capital cost of the system.	X		

5d – Methods overview

The TCT concept operates from the perspective that every possible cost of transportation must be identified and summed to compute the absolute total cost of transportation activity. Absolute costs are grand totals, not differential or marginal values.

Use the following procedure to determine costs:

1. Identify all pertinent cost elements.
2. Find potential sources of data
3. Conduct a data acquisition process
    a) Seek original information to the extent available
    b) Next, extract information from reports based on original data
    c) Measure or locate parties who have measured items for which there is no compiled data
    d) Seek guidance from text books and trade references
    e) Estimate items that cannot be determined in any other way
4. Designate whether each item is a fixed, distance, or time cost.
5. Process the data into unit cost of transportation, $Dollars per VMT, form.
6. Insert the results into a UCT spreadsheet, with a separate value calculated for every level of serve and traffic band combination used in the system physical model.

Chapter 6

DEVELOPMENT OF TCT MODEL FOR IOWA COUNTY ROADS

6 Development of TCT model for Iowa county roads

6a. Overview

In order to test both theory and modeling method, the author elected to analyze Iowa's secondary road system using TCT techniques. This chapter outlines how this was done. There were five basic steps: a) gather basic road and bridge network data, b) develop a physical system model, c) identify and collect cost data, d) process all costs into a 'per VMT' format, and d) combine physical and cost data to set up the analytical framework. (Chapter 7 of the report presents an analysis of the transportation system, based upon the resulting model.)

6b. Setting up the basic model

Work commenced with data acquisition: first, of network data and second, of cost figures. The information was processed into a tabular format that classified system attributes by level of service, (type and quality of road), and by utilization, (AADT – in vehicles per day). Once matching tables of system and cost data had been developed, they were combined to create a final set of analytical worksheets.

6b-1 Source data

System data was relatively easy to obtain because it was already available in a large database at the Iowa Department of Transportation. Gathering and making cost data ready for use took much more effort, due to the fact that there was no convenient central source. It had to be collected, item by item, from a diverse group of independent sources.

6b-1.1 Roads

Road network data was obtained from the Transportation Data section of the Iowa Department of Transportation. This workgroup maintains a large database containing data on every public road segment in Iowa. To assist the TCT study, they extracted all 151,976 county road segment records from the master file and placed them into a Microsoft Access table. Table 6.1 shows the data fields included. Note: field names have been changed, by the author, to make them more self explanatory.

RoadsTBL : Table

Field Name	Data Type	
RdID	Text	County-Twp-Rng-Sec-Rd# road index number. 2-3-2-2-2
County	Number	County ID number
SfcType	Number	DOT surface type code
#Lanes	Number	Number of lanes
Median	Number	Width of the median, if any, in FEET
SfcWidth	Number	Width of trafficway, in FEET
ShldrType	Number	DOT shoulder type code
ShldrWidth	Number	Width of shoulders, in FEET (Multiply by 2 to get total shoulder width)
Curbed	Text	If "Y", then road has a curb along edge of surface
SgmtLen	Number	Length of road segment in MILES
PCCeqv	Number	Est. structural capacity, in INCHES of PCC. (Derived from DOT SNord data fields)
#Bridges	Number	Number of bridges on the road segment
SfcCond	Number	DOT surface condition rating
DrnCond	Number	DOT roadway draining condition rating
AADT	Number	Average annualized VPD count
GrowthRate	Number	DOT AADT growth rate factor

6b-1.2 Bridges

Bridge data was obtained from the same source as the roads data – from the Iowa DOT's Transportation Data section. Per Federal requirements, they maintain records on all bridges, culverts, and overpasses having a span of 20 feet or more. They extracted information on 19,984 such structures listed as being under county jurisdiction, again placing the results in an Access table. Table 6.2 shows the items included:

BridgeTBL : Table

Field Name	Data Type	
County#	Text	
FHWA#	Text	
Underpass	Text	
RtCarried	Text	
MaintBy	Text	Item 21
#Lanes	Text	Item 28a
TypSvc	Text	Item 42
StructTyp	Text	Item 43
StructLen	Number	Item 49
RdwyWidth	Number	Item 51
DeckArea	Number	Derived value : Length x width
StructEval	Text	item 67
CostNew	Number	Derived value : DeckArea * $65
DeprValue	Number	Derived value : CostNew * (StrucEval / 9)

Notes : the Deck Area, CostNew, and DeprValue fields were computed from the raw data supplied by the DOT. Field names have been altered by the author for readability. Underpasses were counted as ½ county responsibility. RCB culvert 'deck area' was figured, by the author, by estimating approximately what size bridge would have been needed if the RCB design had not been used.

6b-1.3 Vehicles

Vehicle data came primarily from the Iowa DOT. The DMV section's web site provided access to a tabulation vehicle types and counts. The main DOT website provided access to a tabulation of annual vehicle miles of travel, VMT, by each major class of vehicle – from motorcycles to tractor-trailer truck combinations. Table 6.3 shows the vehicle types for which data was acquired:

Vehicle Type	**Number**	**Percentage of Fleet**
Total Autos	**2,058,306**	60.20
Small	521,796	15.20
Large	1,151,089	33.60
Multi-Purpose	385,421	11.30
Total Trucks	**797,463**	23.30
3-4 Ton	689,042	20.10
5+ Ton	108,421	3.20
Truck Tractors	12,078	0.40
Total Motorcycles/Mopeds	**128,587**	3.80
Motorcycles	107,473	3.10
Mopeds	21,114	0.60
Buses	8,730	0.30
Motor Homes	22,191	0.60
Total Motor Vehicles	**3,027,355**	88.50
Total Trailers	**390,090**	11.40
Regular Trailers	274,485	8.00
Semi-Trailers	50,245	1.50
Travel Trailers	65,360	1.90
Misc Vehicles	4,188	0.10
Totals	**3,421,633**	100.00

6b-1.4 Drivers

Driver counts and ages were also obtained from the DOT's DMV section.

6b-1.5 Accidents

Accident types and frequencies were extracted from a CD published by the DOT for use with its Access-ALAS accident analysis software. The data is stored on the disk as a set of Access database tables. While this data did link accidents to links and nodes, it was did not prove feasible to compute accident frequencies and severity on a segment by segment basis. Instead, the author chose to compute those factors by surface type and then distribute them across the various level-of-service, LOS, categories in the model as accurately as possible. The data used in TCT was derived from accident reports for 1993 through 1997. Although this predates the 1998 base year used for analysis, the author believes that accident rates are sufficiently stable over time that little error resulted.

6b-1.6 Costs

Cost data for the road network is readily available – but not all from a single source. The author gathered such information from the DOT's Summary of County Engineers' Annual Reports, from Farm-to-Market account reports, and from Federal aid funds programming figures. Cost figures on vehicles, drivers & passengers, accidents, and all the other factors used in this project were obtained from a diverse set of sources, as no central collection of data exists for this type of information. In fact, cost data simply does not exist for a number of factors considered in this project, so a number of them had to be estimated. When this was necessary, the author used personal professional experience to develop values that were as realistic as possible. Such synthetic figures will be subject to refinement when a more direct way of determining their values becomes available. This isn't likely to materially change the results, however, as they proved to be a minor part of the total.

6b-2 Stratification of Levels-of-Service (LOS)

Once the road network data had been collected, the first major task was to establish a way to classify and group road segments by level of service. The use of the term, "Level of Service", LOS, represented a deliberate effort, by the author, to use a broad, total-system perspective. The assignment of an LOS label was intended to imply both the physical character of the route and the level of effort put forth to keep it in serviceable condition. Thus an earth road was viewed as an non-surfaced, low-geometrics facility kept usable only during dry periods of summer and fall, whereas a paved road on a farm-to-market route would provide a stable, high-friction surface, with high geometrics, receiving enough maintenance effort to remain serviceable at least 16 hours per day year round.

Several approaches were evaluated. Use of functional classification categories was considered and rejected because they might contain a degree of built-in bias and because such classifications are sometimes applied more for establishing system continuity than because a segment actually merits the label. Next, the author attempted to devise a continuous scoring system that would numerically represent both road type and level of maintenance – but found that no data on maintenance levels is available on a segment by segment basis. So, the final option was to group roads primarily by type, presuming a level of maintenance for each one.

Another issue was how many -- or how few -- LOS categories should be used. The greater the number, the more refined the analysis could be. But having too many would disperse the road data too much and make it hard to work with. After a number of tries, a set of 14 LOS categories was selected as best able to represent the full range of county road service levels while still keeping the data groupings dense enough for sound analysis.

Table 6.4 shows the LOS categories selected by the author for use in the county road model:

LOS#	Surface type	Sfc Class	Num. of lanes	Median width	Roadway width	Shoulder type	Shoulder Width	Top avg speed	Max q (vph)	Winter Maint.	Annual days closed	Flood freq.
14	Paved - 4L divided & up	7	4	15	48	2	10	65	6000	Top priority	2	100
13	Paved - four lane	7	4	0	48	2	10	62	3000	Priority	2	100
12	Paved - three lane	7	3	0	36	2	10	60	1700	Priority	2	75
11	Paved - 2L - Level 3	7	2	0	26	2	10	55	1500	Priority	3	50
10	Paved - 2L - Level 2	6	2	0	22	2	6	50	1400	Priority	3	50
9	Paved - 2L - Level 1	5	2	0	20	2	4	45	1265	1st day	4	50
8	Hard surface - Level 2	4	2	0	26	2	2	43	1200	1st day	4	40
7	Hard surface - Level 1	4	2	0	22	2	2	41	1000	1st day	4	40
6	Granular - Level 3	3	2	0	29	2	1	40	700	1st day	5	25
5	Granular - Level 2	3	2	0	25	2	1	37.5	600	By 2nd day	6	25
4	Granular - Level 1	3	2	0	21	1	1	35	500	By 3rd day	7	25
3	Earth - 2 lane	2	2	0	22	1	1	25	300	No svc	120	10
2	Earth - 1 lane	2	1	0	12	1	0	15	150	No svc	180	10
1	Earth - unimproved	1	1	0	8	1	0	5	50	No svc	240	5

6b-3 Stratification of traffic volumes (T-bands)

The road segment data also had to be classified into traffic level groupings, or ‘T-bands’. Several approaches were considered: a) analyzing the data to see if there were any natural breakpoints or stratifications of traffic levels, b) breaking traffic into decade ranges of 10’s, then 100’s, then 1000’s, or using a geometric formula to divide the range of traffic levels into proportionately sized bands.

The last option was chosen on the basis that it would be least likely to introduce any bias into the final results and would provide small ranges at low levels while expanding to larger ranges at higher volumes.

The actual determination of Traffic Bands was accomplished by breaking the range of AADT values into twenty logarithmically proportionate groups, of which 19 were actually used. Table 6.5 shows how this was done:

	Trial inputs			Selected band values		
T-band	Log 10 values	Log 10 diff.	Power of ten values	Lower T-band limit	Upper T-band limit	T-band average
1	1.00		10	0	5	2.5
2	1.18	0.18	15	6	13	9.5
3	1.36	0.18	23	14	23	18.5
4	1.54	0.18	35	24	35	29.5
5	1.72	0.18	52	36	52	44.0
6	1.89	0.18	78	53	78	65.5
7	2.07	0.18	116	79	115	97.0
8	2.24	0.18	174	116	175	145.5
9	2.42	0.18	260	176	260	218.0
10	2.59	0.18	389	261	390	325.5
11	2.77	0.18	582	391	580	485.5
12	2.94	0.18	871	581	870	725.5
13	3.12	0.18	1303	871	1300	1085.5
14	3.29	0.18	1950	1301	1950	1625.5
15	3.47	0.18	2917	1951	2920	2435.5
16	3.64	0.18	4365	2921	4365	3643.0
17	3.82	0.18	6531	4366	6530	5448.0
18	3.99	0.18	9772	6531	9770	8150.5
19	4.17	0.18	14622	9771	14620	12195.5
20	4.34	0.18	21878	14621	21880	18250.5

Note: Some minor deviations from true logarithmic ranging were made in Bands 1 & 2 because DOT traffic data is only recorded as 0, 5 or 10 at the very low end.

6b-4 Preparation of data for analysis

Once the methods for deciding LOS and T-Band classifications had been developed, they were assigned to each road segment – which were, in turn, grouped by LOS & T-Band. The sum of their mileages was computed and copied into a table where the rows represented LOS categories and columns corresponded to T-Bands. This table, when complete, provided a compact model of the county road transportation system.

6b-4.1 LOS assignments

Level of Service assignments were made as follows:

a) A special table was set up in the data base to assist in converting DOT base record surface types to a numerically sequenced coding and assign a structural value to the segment's surfacing. Table 6.6 shows the values used in that table:

Table 6.6 - Surface Numbers for DOT codes

Dot Surface Type Codes	DOT Surface type description	Assigned TCT Surface Class	Estimated Structural Value, in inches of PCC
0	Unimproved	1	0
1	Primitive	1	0
2	Earth - Unimproved	1	0.00
3	G&D earth	2	0.01
4	G&D earth w/borrow toping	2	0.01
6	G&D earth w/ admix	2	0.01
20	Granular	3	0.02
21	Granular / admix unknown	3	0.02
22	Granular / admix	3	0.02
41	Mixed Bituminous	4	0.10
51	Bituminous penetration	4	0.10
30	General Bituminous	4	0.20
31	Bituminous on rock base	4	0.30
32	Bituminous on admix rock base	4	0.50
61	ACC / soil base	5	1.60
63	ACC / granular base	5	2.00
60	ACC / general	6	2.60
64	ACC / admix granlr base	6	2.90
72	PCC/ Old type	6	3.20
69	ACC / ACC	6	3.40
62	ACC / admix soil base	6	3.50
65	ACC / Old PCC	6	3.50
67	ACC / PCC reinf	6	3.90
66	ACC / PCC non-reinf.	6	4.20
70	PCC	7	5.00
71	PCC Spcl	7	5.90
74	PCC / New type	7	5.90
75	PCC / New type part reinf	7	5.90
79	PCC / ACC	7	5.90
92	Comb ACC / ACC	7	7.10
76	PCC / New type full reinf	7	7.30
77	PCC / Spcl resurf	7	11.00

b) Using the table from a), a query was run to associate a surface code and structure value with every road segment.

c) A secondary query then generated a level of service 'score' for each record, using the following data items:

Surface Class [from Tbl 6.6] x 100000
+ No. of Lanes x 10000
+ Median Width x 100
+ Surface With
+ Shoulder Width Equivalent

Every segment ended up with a six digit value representing the level of service that it provides. In determining this value, surface class was of first importance, followed, in order, by number of lanes, median width, and width of the traveled way. The author believes that these items correlate well with other attributes, such as horizontal and vertical geometry, safety features, and maintenance level.

d) Last, another query, using a table that associated ranges of level-of-service scores with specific LOS categories, assigned a specific LOS to each segment. See Table 6.7

Table 6.7 – LOS score range table

LOS#	Surface type	Sfc Class	# Lanes	Median width	Sfc Width	Shldr type	Shldr Width	Avg. score	Min Score	Max Score
1	Earth - unimproved	1	1	0	8	1	0	110008	**0**	**199999**
2	Earth - 1 lane	2	1	0	12	1	0	210012	**200000**	**219999**
3	Earth - 2 lane	2	2	0	22	1	1	220023	**220000**	**299999**
4	Granular - Level 1	3	2	0	21	1	1	320022	**300000**	**320024**
5	Granular - Level 2	3	2	0	25	2	1	320026	**320025**	**320028**
6	Granular - Level 3	3	2	0	29	2	1	320030	**320029**	**399999**
7	Hard surface - Level 1	4	2	0	22	2	2	420024	**400000**	**420026**
8	Hard surface - Level 2	4	2	0	26	2	2	420028	**420027**	**499999**
9	Paved - 2L - Level 1	5	2	0	20	2	4	520023	**500000**	**599999**
10	Paved - 2L - Level 2	6	2	0	22	2	6	620026	**600000**	**699999**
11	Paved - 2L - Level 3	7	2	0	26	2	10	720032	**700000**	**720037**
12	Paved - three lane	7	3	0	36	2	10	730042	**720038**	**739999**
13	Paved - four lane	7	4	0	48	2	10	740054	**740000**	**740099**
14	Paved - 4L divided & up	7	4	15	48	2	10	741554	**740100**	**999999**

6b-4.2 T-band assignments

Two queries were used to assign traffic bands to the road segments. The first extracted AADT vehicle-per-day figures from the main Roads table. The second combined the result of the first query with a table associating VPD ranges with each Traffic Band.

6b-4.3 Bridge data preparation

The bridge data was not immediately usable upon receipt from the DOT. It contained a number of city structures inspected by counties as well as county owned facilities. Screening out the city records reduced the total count from 19984 to 18895. In addition, not all bridge data was complete so records were repaired, when the value of the missing data was discernable, or eliminated. This affected about 100 structures.

6b-4.4 Consolidation

After all the preparatory work, a final query combined the road, bridge, LOS, and Traffic-band data into a single new table. The number, length, and deck area of bridges was appended onto each road segment record.

6b-4.5 Extraction of final table

Finally, a Microsoft Excel spreadsheet pivot table query was run to sum the road miles into each LOS / T-band category available. The resulting cross-tabulation established the format for both the physical system model and the subsequent cost tables. Another pivot table run computed the average sq. ft. of bridge deck per mile of roadway in each category – to serve as a basis for adding bridge costs into the overall roadway costs.

6c. Creation and setup of UCT table

Once the physical modeling established the framework, the next task was to obtain cost data and process it into tables of similar form and size. Per chapters 4 and 5, the objective was to acquire pertinent cost data, segregate it into fixed, travel-distance based, and travel-time based groupings, then distribute it across the array of LOS and T-bands. When complete, each set of cost calculations resulted in an estimated total cost per vehicle mile of travel, or “Unit Cost of Transportation, UCT, for each LOS – T-Band combination.

6c-1 General plan

The UCT worksheet was set up as follows. It had a top level page for totalizing final results from seven source pages, each of which dealt with a specific class of expense: Roads & Bridges network, Vehicles, Human resources, Economic Costs, Social & Environmental Costs, and Cost offsets. All eight pages included a general purpose work area and three columns of cost tables: one for fixed costs, one for travel distance based items, and one for travel time based expenses. From there, the effort was to find sources of cost information and include the appropriate figures in the UCT worksheets in per-VMT form, then sum them by major class, then totalize all three classes on a page, and then totalize all seven source pages into the final results page.

6c-2 Road & Bridge network costs

Road and bridge costs were compiled from a number of sources: the 1998 DOT Summary of County Engineers' Annual reports, from 1999 Farm-to-market account expenditures, from 1999 Federal aid programming, and from the DOT's source materials compiled for the Quadrennial Needs Study. Capital values of and depreciation rates of the road/bridge network were estimated by the author, based both and raw quantities and on the DOT 1998 Needs Study data. After the data had been acquired, it was apportioned into the following categories via a large supplemental worksheet: Administration, Engineering, Cost of Capital, Annual Depreciation, operations, maintenance, repairs, and supplemental. Care was taken to assure that the final results added up to the same grand total as all original inputs and that, if two sources of data existed for any item, that any difference was explained and eliminated.

6c-3 Vehicle costs

Vehicle cost figures were derived primarily from raw registration counts and the DOT's VMT by class of vehicle estimates. The basic procedure went as follows:

a) Used DOT data on rural VMTs by vehicle type to estimate the mix of types on each LOS category.
b) Computed age, costs, miles per year, and estimated lifetime for each vehicle type.

c) Individually computed the UCT costs for each of the following items:

Cost of capital -- ROI on depreciated asset valuation
Annual depreciation -- capital replacement cost
Operations, maint, repair & accessories
Maintenance and repairs
Accessory purchases
Towing and Road Service
Final disposal
Legal framework
Financial framework
Govt. DMV administration
Law enforcement regarding vehicles
Vehicle research not included in purchase price
Base of operations
Media & Advertising
Transaction & trade costs

6c-4 Human resource costs

Driver and passenger economic costs per hour of driving were determined estimating hourly pay rates for occupants of each class of vehicles, then determining what percentage of the driving population is engaged in 'for-pay' type activities when traveling upon a road of any particular LOS class. This resulted in a composite, per hour figure that could be divided by average miles-per-hour travel speeds to get a cost per mile of travel. Items included in this calculation were:

Wages and benefits
Labor administration
Labor overhead expenses
E.C. of driving & licensing legal framework
Administration of drivers licensing

6c-5 Accident costs

The ALAS accident data was processed into TCT model form via a large supplemental spreadsheet. This worksheet took the original data and processed it into accident, fatality, major injuries, minor injuries, and property damage rates for each type of roadway. Per incident cost figures were applied to the rates of occurrence to compute average annual costs per vehicle mile of travel on each surface. The average cost per accident turned out to be nearly the same, around $20,000, for all surface types and levels of service. It was the accident frequency that varied with LOS and/or traffic levels.

Determining the true economic cost of fatalities proved to be a major challenge in computing accident costs. As far as the author could tell, figures recommended by State and Federal authorities should be taken to be policy statements instead of actual economic cost measurements. They declared that a fatality should be deemed to cost society $500,000, $800,000, or $1,000,000 per incident – serving as a statement of how badly society wants to reduce fatal highway accidents by justifying the large expenditures for roadway safety features required to reduce fatality rates. Since the TCT method is intended to be based on actual, real costs, an independent effort was made to review the cost of fatalities. This was accomplished via a supplemental worksheet that estimated the loss to society when people die prematurely due to auto accidents or any other cause. Using average per capita incomes for Iowa and the age distribution of fatality victims, the analysis indicated a true, economic cost, in this state, of around $166,571 per fatality. It also suggested that the greatest loss occurs when a 29 year old person dies -- because individuals in that age range are just starting to make their full contribution to society's collective wealth after 'paying off' the accumulated support 'debt' incurred during their developmental years.

The difference between the 'actual' cost computed in this project and the officially recommended fatality loss figures shows how earnestly society wants to reduce the annual death toll on our nation's highways. Despite the disparity, TCT used the lower number to stay true to the 'real' costs perspective of the concept. The sensitivity of overall TCT costs to the cost per fatality value will be explored in Chapter 7.

6c-6 Economic costs

From the TCT perspective, economic costs are expenses derived from adapting pubic and private facilities to make use of the benefits of the road network and vehicle fleet. Many of the items identified in this area weren't relevant to county roads, but cost figures were developed for those that are. Table 6.8: (Boldface items were included in this project's analysis)

Table 6.8 – Economic costs of transportation
Docks, transfer stations, warehouses, load-unload facilities
Drive up service sites: restaurants, ATM's, etc.
Logistics
En-route food, rest stops, lodging
Communications services
Outdoor signs and advertising
Motor clubs, traffic info services, maps
Media
Cargo : Cost of capital
Cargo : Depreciation in transit
Cargo : Loss and breakage en-route

6c-7 Social/Environmental costs

Social and environment costs are the sum of what society must spend to overcome adverse impacts of the road based transportation system. Of the items listed in Table 6.9, only the cost of fugitive dust was processed into this project. The other items are all of very minor consequence on low volume roads.

Table 6.9 Social / Env. Cost categories
Cost of restoring non-RBTS links
Increased cost of utility extensions
Cost of business disruptions
Fugitive dust
NO/VOC air pollution
Noise pollution
Visual blight
Water pollution

6c-8 Cost offsets

Finally, to some degree, the presence of a low cost transportation system produces offsetting benefits that need to be deducted from the total cost of the system. For instance, Iowa's well maintained rural road system permits agricultural producers to gain bigger yields by being able to access fields on a timely basis in spring and fall. And a manufacturer can keep inventory costs down or have fewer factories if they can rely on transportation to assure timely shipments year round. Private sector savings in these areas were estimated and subtracted from the total cost of the other six.

6d. Implementation of time sequence modeling

Representing changes in the physical model over time can be implemented in two ways. The more fundamental method is to multiply the AADT values for each road segment by a factor computed from the segment's growth rate and number of years elapsed. For instance, if the segment has annual growth of 2.5% and we want to model the passage of five year's time, we'd multiply the current AADT by $(1.025)^5$. When applied across all segments, this calculation will have the effect of shifting some segments into higher traffic bands. This right-shifting of miles also models the gradual development of need for improvement due to traffic growth. A similar approach could also model changes in condition.

An alternate way to model traffic increases over time is to perform the adjustments on the LOS / T-Band spreadsheet itself. This leaves the segment information in the database untouched. In this approach, one would need to compute an average annual growth rate for each LOS / T-band combination. The calculations would then proceed from the rightmost column in each row, cell by cell to the most left hand column. Presuming that the distribution of travel levels is uniform within a band, one would multiply the total miles by the growth rate, then subtract that amount from the current cell and add it to the total of the cell immediately to the right. This shifts an appropriate amount of mileage into the next higher traffic band. Then one would shift one cell to the left and repeat the process. Mileage from that cell would then partly or fully replace the mileage lost from the first one in the previous calculation.

The segment based approach is the best, but requires truly accurate traffic counts to work correctly. The cell by cell approach is fast and would be the best for processing data where traffic counts tend to be rounded off to standard values. The road records received from the DOT are of mixed quality: in the lower traffic ranges, the DOT tended to artificially round counts to the nearest 5 or 10, but in the higher volume bands, the counts fall into a more or less evenly dispersed pattern.

6e. Modeling of the cost to make improvements

An important part of any decision making support system is to be able to compare the estimated cost to improve a facility versus the savings that will arise from doing so. In this project, the cost to upgrade from one LOS to another was computed by subtracting one half of the cost of constructing the old LOS new from the full cost of constructing the new LOS on new alignment. This approach was chosen because the annual depreciation cost for each LOS covers the cost of periodically restoring the roadways back to original condition. Thus an improvement's net cost is the additional amount of capital that must be added to that derived from the depreciation. The decision to deduct only half the new cost of the old LOS was made to account for the fact that reconstruction isn't simply additive: it always involves partial destruction of the old facilities.

TCT also recognizes that it is occasionally advisable to downgrade a road segment, especially when traffic levels have substantially decreased, as might happen when an old route is bypassed. Example: a jurisdiction might revert an old section of pavement back to gravel – both to decrease future patching costs and to eliminate the need for sanding and salting the route in winter conditions. So the cost-to-improve table also includes estimated costs for level of service reductions. These were estimated to be ½ (New cost of current LOS – New cost of lower LOS). This reflects the reality that it is much easier to downgrade than to upgrade.

The amounts derived from these estimates were compared to and found to be in line with new construction costs utilized in the 1998 DOT Quadrennial Needs Study.

6f. Modeling road improvements

Improvements can be modeled at the spreadsheet level by subtracting mileages from one LOS within a traffic band and adding them back into a higher LOS. Alternately, one can identify specific road segments and update their physical parameters to match those as constructed or typical of the new LOS. In the secondary option, the full set of LOS / T-band assignment and classification queries will need to be rerun in order to get the results to reflect in the spreadsheet. Generally, people would be advised to use the spreadsheet basis when studying broad, system-wide strategies and use the segment update approach when selecting or modeling specific projects.

6g Summary

As described in the preceding subsections, the task of setting up a TCT model for analyzing Iowa's County Road system consisted of three major parts:

a) Setting up a physical model
b) Computing per-VMT, or "Unit Cost of Transportation", cost figures
c) Tabulating the costs to upgrade, or downgrade, from one level of service to another

6h List of database and spreadsheets

The database tables and queries, plus the spreadsheets used to create the county roads model have been written onto a CD-ROM disk and included with each bound volume of this report. The following summary explains how they were utilized:

TABLES:

Tables contain static data and are used by queries to extract intermediate and final results.

1. Basic data table

   The following tables contain the raw road and bridge data received from the Iowa DOT.

   a. RoadsTBL – contains data on 151976 county road segments
   b. BridgesTBL – contains data on 19984 bridges owned or inspected by counties
   c. Rd~BrXrefTBL – a cross reference table that links each bridge to a specific road segment.

2. TCT classification tables

   These tables contain synthetic data that was developed by the author to facilitate processing the basic network data into a format suitable for TCT analysis

   a. TffcBandsTBL – specifies the minimum and maximum vehicles-per-day, vpd, limits for 21 possible traffic bands, numbered from 1 to 21. (In practice, it was found that the two highest bands were not needed for county road analysis.)
   b. LOS#forDOTcodesTBL – links a TCT surface type number and PCC thickness equivalency factor to each of the 32 surface types contained in the DOT base record data. Used in the process of assigning LOS numbers to road segments.
   c. LOS_Bands_TBL – specifies a minimum and maximum point 'score' for 14 possible Levels-of-Service, (LOS). Used, with 2b. above, to assign LOS numbers to each road segment.

QUERIES use special rules to associate data of one table with that of another, then filter and sort the results. When a query is complete, a dynamic table, or record-set, presents the results. This record-set may be queried by other queries as if it were another table. TCT used a cascade of two, three, or four queries to process the source data into useable form. The queries were run in the sequence outlined below:

3. Traffic Band Assignment queries

   These queries used both original table data and intermediate query results to compute and assign a discrete traffic band number to each road segment.

   a. EstVPD_QRY -- This query applies each road segment's rate-of-traffic-growth factor to the segment's base year AADT to compute an estimated, future AADT figure. This enables analysis of the transportation system at future points in time or to study changes taking place over a time interval. The query uses the RoadsTBL, 1a., to obtain and use Road ID, AADT, and growth rate data.

   b. TrafficBandAssignmentQRY – Screens the results of the EstVPD_QRY, 3a., against the TrffcBands_TBL, 2a., to determine and set the appropriate traffic band for each road segment

4. Level of Service Assignment queries

   A sequence of three queries was required to assign a LOS number to each road segment.

   a. LOS_Calc_BasisQRY – Used the RoadsTBL, 1a. and the LOS#forDOTcodesTBL, 2b., to pull together the data needed to compute a Level of Service score for each road segment.
   b. LOS_Number_Calc_QRY – Used the results of 4a. to compute a six digit numeric level-of-service score for each segment, based on surface type, number of lanes, median width, structural capacity, and shoulder type-width.
   c. LOS-RdID_XrefQRY – Used the results of 4b. with the LOS_BandsTBL, 1c., to associate a discrete LOS classification to each road segment.

5. Bridge information calculation and allocation queries

   a. BridgeInfoQRY – Used the RoadsTBL, 1a., BridgesTBL, 1b., and Rd~BrXrefTBL, 1c. to compute the number, total length, and total square feet of deck area of bridges for each road segment. Filtered out city bridges, resulting in a final count of 18895 structures.

QUERY CASCADES -- It should be noted that, once queries are set up, it is not necessary to execute each one by hand. Instead, opening any one query causes it to open and execute all prior queries that it depends on. So, when a user specifies that the LOS-RdID_XrefQry, 4c., be run, the system first runs the LOS_Calc_BasisQRY, 4a., then the LOS_Number_Calc_QRY, 4b., and then finally 4c. While this feature assures that the final result is based on the most current data available in the source and classification tables, there is a down side: with everything being recalculated in sequence, it can take up to 10 minutes for the final results to appear. If one needs to look at the final results in several different ways, such delays greatly retard progress. Since this was the case with the TCT data, the author chose to use a final query to consolidate the results and save them into a new, static table. This made it much easier to analyze the system – but did require that the consolidation be rerun anytime that source data items were changed.

6. Consolidation query -- The MakeRdTBLOSXref_QRY query combined the results of the TrffcBandsAssignmentQRY, 3b, the LOS_RdID_XrefQRY, 4c., and the BridgeInfoQRY, 5a, with the original RoadsTBL, 1a., data to generate a new, stand-alone table for analysis. The resulting "Rd_Tbd_LOS_Xref_TBL" brought together the Traffic band and LOS assignments for each road segment, setting the stage for generating a tabular representation of the road and bridge network by traffic levels.

7. Creation of final cross tabulation between LOS and traffic bands – Once a T-band and LOS had been associated with each road segment, the final task was to create a table to represent the system. The objective was to let the table's rows represent LOS settings while the columns represented the Traffic bands. Thus arranged, each cell of the table could be used to contain a numeric value representative of some aspect of the system.

   To complete preparations for TCT analysis, two major abstractions were developed from the consolidated data:

   a. Mileage by Traffic band and LOS : An EXCEL "Pivot Table" worksheet was set up to find all the road segments belonging to each T-band/LOS combination and then sum their mileages. This produced a cross-tabulation that presents system size and activity levels in a two dimensional format.

b. Bridge deck area per mile of road: A second pivot table was used to extract the total square feet of deck area for the road segments in each T-band/LOS cell of the table. These results were then divided by the results of the previous pivot table.

The two tables provided a workable representation of the transportation system and established the format in which the costs of transportation should be collected.

8. After cost data was developed, another table, the “Cost to Upgrade/Downgrade from one Level of Service to another” table was prepared to enable segment specific analysis of improvement options, costs, and benefits. The details of this are contained in Chapter 7.

Chapter 7

ANALYSIS OF IOWA COUNTY ROAD ISSUES WITH TCT

111207 Analysis of Iowa county road issues with TCT

7a. General results and observations

This section used the TCT physical and cost model of Iowa's county road transportation system, developed per Section 6, to investigate a wide variety of system design and administration issues. The goal was be to find out what could be learned from and done with TCT methods. It was be an exercise in determining where the concept shows utility and where it does not.

> **Special caveat:**
> Along the way in this "proof of concept" effort, TCT methods was utilized to draw conclusions about a variety of road design and administration issues. While the author believes that the work showed that TCT is a valid and pertinent tool, readers should not take any specific conclusion about the county road network as final. This research effort spanned six years and, while most data used herein was less than four years old when Chapter 7 was developed, it was not fully current. This situation didn't impair the ability to evaluate concept and tools because dated figures work as well as fresh information for that purpose. But it does mean that the source data would need to be updated before anyone could draw fully authoritative conclusions about the system and segments themselves.

The results obtained from the Database & Spreadsheet model used to implement the TCT concept come in the form of a large number of large tables. The tables were mostly too wide to be legibly printed on letter or legal size paper, so they were placed on 11" x 17" tabloid size sheets, which were collected into a supplemental booklet. The text of this section will make frequent reference to the tables in that supplement. Readers must, therefore, keep a copy available for inspection as they read the following sections.

The two key components of the trial TCT model, the Physical system model and its Cost of transportation twin were developed from a wide variety of source data. In many instances the information was not received in a form that could immediately be worked with. When this happened, special queries and/or spreadsheets were employed to convert it into proper form. While these "behind the scenes" preparations will not be presented in full detail in this report, the tables and files involved will be available for inspection on the research report CD.

7a-1 Physical model

The Physical model's purpose is to abstractly, yet accurately, represent the size, configuration, and dynamics of the system being studied – which in this project was Iowa's approximately 90,000 mile county road network and associated traffic.

After pre-processing the road and bridge network data in the Database part of model, an EXCEL pivot table was used to generate a base table that then served as the foundation for all the others. The base table modeled both the fixed base of roads & bridges as well as the vehicular activity operating upon that network. *[Refer to Table 7-1 in the Supplement].*

As described in Chapter 6, fourteen rows were set up to represent the range of road network 'Levels-of-service' (LOS), from Unimproved to Paved – 4 Lane –Divided. Nineteen columns were used to break up the range of possible traffic volumes, (from 0 to 14620 vehicles per day), into logarithmically proportionate "Traffic bands" (T-bands). This resulted in 266 cells, each associating a LOS with a specific T-band. Then each road segment from the DOT base record was tagged with both a LOS and T-band rating, and sorted, first by LOS and then by T-band, so as to group segments with identical LOS/T-band characteristics together. The individual lengths of the like segments were summed and placed into the spreadsheet cell corresponding to their LOS/T-band values.

The resulting grid represents the size and configuration of the road network via the row, or LOS, totals. The level of activity using the roads is modeled by how much mileage falls within each T-band column. Multiplying any cell's miles value by the average VPD value of the cell's T-band will estimate the daily vehicle miles of travel (VMT) taking place, collectively, on the road segments involved. (Multiplying that result by 365 gives annual VMT).

In *Table 7-1*, mileages were totaled and annual VMT was computed for both all LOS's and T-bands. At the right-hand side total VMTs for each LOS were divided by total mileage in that LOS to compute an average VMT per mile of road per day.

Inspection of the resultant table reveals the following:

- Although there is a fair amount of dispersion, each T-band tends to have two or three LOS settings that contain the majority of the miles for that traffic range. (See the cells outlined with the heavy lines). This shows what levels of service road designers have historically felt best met the needs of the traveling public. Their collective choices have been approximately as follows:
    - 0-5 vpd: Provide earth surfaced roads
    - 5-23 vpd: Provide earth or gravel, depending on circumstances
    - 23-78 vpd: Provide gravel surfaced roads
    - 78-260 vpd: Designers have been somewhat divided on what level of service to provide in this traffic range: the majority have opted to stay with granular surfacing, but many have also chosen pavement.
    - Very few miles of hard surfaced roads have been built or retained
    - 260-9770 vpd: Provide two lane paved roads
    - 9770 & higher: Provide four lane roads
- The top 50% of annual system VMT is carried on just 7.8% of the total mileage.
- The bottom 50% of the mileage carries only 8.4% of the total VMT.
- (There evidently are a few errors in the base data: For example, the table shows that there are 0.95 miles of the Unimproved LOS category serving T-band 10 traffic levels – from 260 to 390. That almost certainly has to be wrong. There are, no doubt, some mistaken road segment data items, too. The existence of such errors is not a large problem, but does need to be remembered when interpreting results.)

These observations seem consistent with the fact that the county road network consists of a large number of very low volume land-access roads that feed into a set of collector roads which then carry rural traffic to/from towns or state highways.

Table 7-1 cannot fully model the transportation system by itself, so additional tables are required:

7a-1.1 Travel speeds *[Refer to Table 7-2 of the Supplement]*

VMT figures indicate how much traffic there is but not how fast it moves, so *Table 7-2* was devised to model average speeds for each LOS/T-band combination. The speeds shown in the table were developed by the author based on personal knowledge of county roads as a former County Engineer, with some guidance from the Highway Capacity Manual. The basic concept is that traffic flows at a free-flow speed until the VPD reaches some threshold level. From then on, speed gradually declines with increasing volumes. The HCM formulas suggested general principles but could not be directly used because a) county road volumes are so low as to be "off the scale" of most HCM formulas and b) TCT needs to model the AVERAGE speed of travel from origin to destination – not spot speeds en-route. To better explain: the speed figures in *Table 7-2* are intended to represent the total annual VMT in each LOS/T-band grouping divided by the total number of vehicle hours spent traversing the road segments in question. Because a vehicle cannot move at design speed at all times, gets delayed by slower vehicles, and loses time at intersections, the average speed of travel always falls below design speed and speed limits.

7a-1.2 Vehicle fleet makeup

The next element of the system that needed description was the relative proportions of different vehicle types within the fleet operating upon the roads and bridges. To that end, the author employed a vehicle types breakdown adapted from a DOT needs study on truck percentages. Vehicle storage (garaging) and parking quantities, (at both the vehicles' base of operations and at destinations), were also estimated.

The vehicle mix used in the model was as follows: Figure 7-1

LOS	Vehicle types	Autos	Pick-ups SUVs	Lt Trks	Heavy Trucks	Tractor Trailer units	Buses	Agri. equip ment	Motor cycles	Total
14	Paved - 4 lane - divided	61.0	17.0	8.0	4.1	3.9	3.0	1.0	2.0	**100.0**
13	Paved - 4 lane	62.5	17.2	7.1	3.9	3.8	3.0	1.0	1.5	**100.0**
12	Paved - 3 lane	65.0	16.4	6.5	3.8	3.3	3.0	1.0	1.0	**100.0**
11	Paved - 2 lane - Level 3	66.0	17.3	6.0	3.5	2.9	2.5	1.0	0.8	**100.0**
10	Paved - 2 lane - Level 2	67.0	17.8	5.4	3.2	2.6	2.5	1.0	0.5	**100.0**
9	Paved - 2 lane - Level 1	68.2	18.0	4.8	2.8	2.4	2.5	1.0	0.3	**100.0**
8	Hard Surface - Level 2	65.9	22.2	4.2	2.5	2.1	2.0	1.0	0.1	**100.0**
7	Hard Surface - Level 1	65.9	22.4	3.6	2.1	1.9	2.0	2.0	0.1	**100.0**
6	Gravel - Level 3	65.9	22.6	3.0	1.8	1.6	2.0	3.0	0.1	**100.0**
5	Gravel - Level 2	65.9	22.8	2.5	1.5	1.2	2.0	4.0	0.1	**100.0**
4	Gravel - Level 1	65.4	23.9	2.0	1.3	0.8	1.5	5.0	0.1	**100.0**
3	Earth 2 lane	57.9	33.9	1.0	0.8	0.3	0.0	6.0	0.1	**100.0**
2	Earth 1 lane	51.4	39.5	0.6	0.3	0.1	0.0	8.0	0.1	**100.0**
1	Unimproved	44.6	44.8	0.2	0.2	0.1	0.0	10.0	0.1	**100.0**

7a-1.3 Number of occupants and purpose of trips

Since vehicles are operated by drivers and carry passengers, the number of occupants and the reasons for their travel were modeled. People make automobiles trips about two thirds for personal purposes and one third for work and business. At the other extreme almost all trips made by heavy truck driver are work related. To account for these variations, the human resource model estimated the percent of trips, for each type of vehicle, which involved paid time, the approximate occupancy rates typical of such trips, and average pay rates of all those people who were receiving wages while en-route.

The trip purpose breakdown was as follows: Figure 7-2

	Auto	Pkp / SUV	Lt Trk	Hvy Trk	Semi	Bus	Ag	Cycle
Trip purpose Pct work related (by vmt)	34%	44%	56%	85%	95%	95%	95%	5%
Avg. # pd occupants	1.2	1.5	1.5	1.5	1.0	1.0	1.0	1.0
Avg occupant pay rate	$13.46	$12.02	$12.02	$12.02	$16.83	$12.02	$ 8.65	$13.46

(When these figures were combined with the fleet breakdown, and employer paid labor costs were factored in, the average labor cost per vehicle hour of travel could be computed for all 14 levels of service.)

7a-1.4 Accident frequency and severity

Since accidents are an unfortunately significant characteristic of the transportation system, the frequency and severity thereof were modeled for each Level-of-Service – starting from raw accident data provided by the Iowa DOT – in the form of their Accident Location Analysis System (ALAS), files. Values were determined for each of the 14 LOS categories in the model and then validated against actual totals.

The resulting accident frequencies used in the model were as follows:

Figure 7-3 :Accident rates - per Million VMT

LOS #	Accident class:	Estimated frequency of all type acc.
14	Paved - 4 lane - divided	0.626
13	Paved - 4 lane	0.960
12	Paved - 3 lane	1.253
11	Paved - 2 lane - Level 3	1.587
10	Paved - 2 lane - Level 2	2.297
9	Paved - 2 lane - Level 1	2.506
8	Hard Surface - Level 2	2.631
7	Hard Surface - Level 1	2.652
6	Gravel - Level 3	2.666
5	Gravel - Level 2	3.602
4	Gravel - Level 1	3.854
3	Earth 2 lane	3.372
2	Earth 1 lane	0.920
1	Unimproved	0.613

The lower rates for LOS 1 and 2 may be statistical aberrations or may result from the fact that such roads are in such poor condition that it's hard to go fast enough to have accidents.

7a-1.5 Non-road fixed-base items necessary to the functioning of the system

Last, efforts were made to obtain valid counts of fixed base items that are part of the overall system, such as drive-up ATM's, fast food take out windows, loading docks, and the institutional / financial framework necessary for the system to function.

The vehicle, people, accident, and fixed-based physical model elements were used to determine transportation costs resulting from their operation upon the road and bridge netowork.

7a-1.2 Other features and attributes modeled

Several other dimensions of the system were also modeled within the database and/or spreadsheets. These items included:

- **Percent growth rates:**

  The DOT base records contain an estimate of annual year to year traffic growth rates for each segment. These factors vary with type, location, and existing traffic levels. This data was used for the time interval analysis work discussed in the final section of this chapter. The factors were developed over time by the DOT. The author did not investigate how this was done but the data was examined, found consistent with his past experience.

- **Congestion :**
  While this item is not typically encountered in county road situations, it was able to be indirectly modeled via the average travel speeds table: as traffic volumes grow, overall speeds decline, leading to increased time consumption between origin and destination.
- **Structures:**
  Bridge counts, sizes, and conditions where accounted for by computing a "square feet of bridge deck per mile" average for each LOS/T-band combination and then computing average degree of depreciation based upon bridge inspection report ratings.

7a-1.3 Items not modeled

It is equally important to note what elements of the overall system were not explicitly included within the model set up for this research effort:

- **Condition states:**
  This study treated the road and bridge network as if all components were operating at an average, roughly steady state condition in each LOS/T-band category. While this is accurate enough for short term analysis, study periods in excess of five years would probably need to be able to represent the conditions of the assets more specifically. To do this, one would need to have an objective method for determining numerical condition ratings and then add a third dimension to *Table 7-1*, so that the miles within each LOS/T-band could be divided up into five or more condition state categories.
- **Condition change rates:**
  Once one had the road and bridge conditions cataloged, the next element necessary for accurate modeling would be an estimate of how quickly the condition levels deteriorate over time. This would involve a factor or formula for computing how much mileage drops from higher to lower rating levels each year.
- **Railroad crossings:**
  At grade rail crossings, signals, and over/under passes are system elements shared in-common with another transportation mode. This study did not include any physical model tally of them, nor did it contain any cost figures for them.

- **DNR mandated bridge size increases**

  As bridges are replaced, the Iowa DNR's flood estimation and hydraulic design requirements tend to require that each new structure be longer than the one it replaces. This causes quantity of bridge deck per square mile to grow over time, but this effect was not factored into the trial model

7a-1.4 Physical model summary

The physical model methodology used in this project seems capable of representing almost all size, type, condition, and rate-of-change characteristics of the entire system: roads, bridges, vehicles, activity, speed, time, human resources, accidents, and fixed based elements. This appears to fulfill the goal of adopting a total system perspective.   The factors omitted from this work will enhance the quality of the model, when added in, but aren't absolutely essential – since they can be approximated or treated as roughly stable over time.

This model proved to be a very compact way to represent all aspects of the system in an easy to view and understand format.   Because the base table, *Table 7-1*, is derived from and remains linked to the database of road and bridge base records, the model also maintains a link between the system level and the segment level.

This project's trial model also illustrates that TCT can be implemented as an open system. New system elements and characteristics may be added in as new tables or data fields when identified. Such new information can amplify and improve the model without requiring that the basic structure be reworked. And, as set up, all components are open to easy inspection and review.

7b. Unit Cost of Transportation model

The physical model describes the transportation system in terms of counts, rates, and conditions. A parallel, complementary cost model is needed to define the size and behavior of the system economics. This was accomplished by developing a new table that identified a cost per vehicle mile of travel in each LOS/T-band category of the original base table.

As noted in previous chapters, three major categories of costs exist: fixed, travel distance based, and travel time based. Cost sources included: the road network, the vehicles, paid driver and passenger time, accidents, business and economic factors, and social / environmental impacts. For each source, costs were developed and assigned to the appropriate categories. Each of the major categories was then summed and they, in turn, were totaled into one final set of figures. The table containing all the final totals was given the name of "Unit Cost of Transportation", (UCT) table.
[Refer to Table 7-3 in the Supplement]

One additional, reverse, cost factor was also included in recognition that investments in and money spent to operation the road based transportation system reduce the need for capital investments in and costs of non-transportation alternatives.

7b-1 Overview of cost sources

This section summarizes findings from the actual development of unit costs of transportation for each source.

7b-1.1 Roads and bridges

Road and bridge costs were developed with the assumption that current spending is approximately adequate to maintain current assets in an overall steady state condition and to permit sufficient improvements so as to keep up with traffic growth. If, in fact, current spending is NOT adequate, additional study would be needed to determine what level would be. That might impact the level of service recommendations generated by the model and would increase the need to make predictions about condition states and how they change over time for various funding levels. The author believes that the assumption that current spending would keep the system stable was reasonable for funding levels of the recent past. (Given the RUTF and Federal Aid cutbacks that seem imminent in the 2000's this may not be true much longer.)

As a part of the road and bridge cost work up, the current, the depreciated value of the entire county network was estimated to be around nine billion dollars, $9,000,000,000. The annual cost of capital for this investment was calculated to be about $712 million per year. (This figure represents the return that Iowa could have earned on the capital had it been invested elsewhere.) This exceeds the $453 million spent on county road operations in 1998 by 57%.

7b-1.2 Vehicles

Vehicle per-mile costs proved remarkably uniform, because higher priced units, such as heavy trucks, tend to get driven more miles per year than autos or pickups. As the following mini-table shows, only agricultural vehicles displayed high per mile costs. Figure 7-4

Vehicle type	Auto	Pkp / SUV	Lt Trks	Hvy Trks	Semis	Buses	Ag Equip.	MtrCyles
Total Vehicle UCT	$ 0.45	$ 0.67	$ 0.77	$ 0.75	$ 0.53	$ 0.73	$ 13.15	$ 0.53

When the per mile figures were combined with the vehicle fleet proportions, the average per-mile cost per VMT in each LOS category came out as follows: Figure 7-5

LOS #	Description	Avg $/VMT
14	Paved - 4 lane - divided	$ 0.633
13	Paved - 4 lane	$ 0.630
12	Paved - 3 lane	$ 0.628
11	Paved - 2 lane - Level 3	$ 0.626
10	Paved - 2 lane - Level 2	$ 0.626
9	Paved - 2 lane - Level 1	$ 0.625
8	Hard Surface - Level 2	$ 0.627
7	Hard Surface - Level 1	$ 0.754
6	Gravel - Level 3	$ 0.881
5	Gravel - Level 2	$ 1.008
4	Gravel - Level 1	$ 1.135
3	Earth 2 lane	$ 1.269
2	Earth 1 lane	$ 1.530
1	Unimproved	$ 1.788

It seems plausible that there would be some variation in the per VMT costs according to traffic level, as well as with LOS. But the author found no reliable documentation to verify this, so the model used the same per-VMT cost in all traffic bands of each LOS.

7b-1.3 Human resources

The physical model data on trip purposes and the mix of vehicles in the fleet was used to compute an average, PER HOUR, cost of time spent within a mile of roadway while traversing it. This was done for all 14 LOS categories and produced interesting results: the rate was very uniform, ranging only between $16.18/hr to $17.63 per vehicle hour of travel. The lower values were found on the gravel and earth road types while the higher ones were associated with paved routes. The figures were then divided by AVERAGE speed to obtain the human resource cost per VMT.

7b-1.4 Accidents

Accident costs were quantified by using estimated costs for each type of damage or injury sustained. The ALAS accident data was comprehensive enough to permit computing an average cost per accident for each LOS. As noted in Chapter 6, the figures indicated that accident severities are about the same for all road types, with a representative cost of around $20,000 per incident. This suggests that roadway designs improve highway safety principally by reducing the frequency of accidents – not their severity.

7b-1.5 Economic and business

It was possible to identify many different items that play a role in road based transportation, such as grain scales or drive up service windows, but assigning costs to them and conversion of such figures to a per VMT-form was hard, Quantities of such items are difficult to find and costs are even more elusive. The author obtained as much information as could be found and roughly estimated the Economic and Business figures. While this makes them less reliable, they also turned out to be a minor portion of the overall total. So total-model accuracy was not seriously impaired.

7b-1.6 Social / Environmental

These costs elements exhibited the same problems as described for the Economic and Business factors. This was offset, at least for county roads, by the fact that traffic volumes on such routes are so low that most forms of pollution were too small to quantify.

7b-1.7 Cost offsets

Really reliable data on cost offsets was not available. The author conducted some informal discussions with appraisers and learned that one can say, in general, that land along paved roads sells at a premium to land along gravel or earth routes. With that meager guidance, the author estimated small cost offsets for each LOS category and incorporated them into the final Unit Cost of Transportation totals. As with Economic and Social/Environmental costs, the impact on the find result’s accuracy was minimal.

7b-2 Examination of the final UCT table

After all the cost sources had been quantified and placed into a dollars per VMT form, the results were totaled, producing a table that associates a specific per VMT cost with each LOS/T-band combination. *[Refer to Table 7-3 in the Supplement]*.

7b-2.1 Basic results

An examination of the final UCT table reveals the following:

- VMT costs are highest in the low volume traffic bands and decrease as traffic levels grow, down to just under $1.00 per mile of travel.
- At low volumes, the cost per mile is greater for higher levels of service than for lower ones. This effect decreases until, at around 80 vehicles per day, neither high nor low levels of service offer a cost advantage. From there on, the cost per mile on lower levels of service becomes higher than that on higher level facilities.
- Within each traffic band, one can find a Level-of-Service in which the VMT cost is a minimum. A least cost, or optimal, LOS was determined for traffic-band, using the 'Minimum' value function available in the spreadsheet.
- Once identified, the optimal LOS categories were highlighted to see what pattern they fell into. This revealed an arrangement in a stair-step like diagonal band, starting out at LOS 2 at the low end and rising to LOS 14 at the high end. The pattern isn't smooth: as traffic counts rise, the least cost LOS tends to jump upwards at some point, then stay at the new LOS across several more traffic ranges. This suggests that one can identify what range of traffic is best served by each LOS type.
- An examination of the least cost traffic bands for any particular LOS shows that they typically fall at higher volumes than the T-band analysis would seem to recommend. This appears to be because higher levels of service tend to begin providing the least cost service before any particular LOS reaches its least cost traffic level.
- The optimal LOS/T-band combinations were also highlighted in the base physical model, *Table 7-1*, and the average speed tables, *Table 7-2*. When "historical judgment" based LOS to T-band match-ups are compared to the layout of the least cost combinations, it appears that one could judge that people have under-improved roads in the 35 to 175 vehicles per day range and may have over-improved roads in

the 175 to 580 range. At the higher end, under-improvement appears again, from 2920 vpd and up.

- A review of the average speed table shows that average speed of travel is higher for each succeeding optimal level of service. This implies that higher volumes of traffic *must* be served by higher speed levels-of-service if the total cost of operation is to be minimized.

7b-2.2 Service level evaluations

The existence of a least-cost level-of-service in each traffic band means that all other LOS options generate more cost per mile of travel for that traffic level -- and the model shows that the cost differential increases as road characteristics range further from the minimum cost level's attributes. This suggests that the more tightly a system's mileage is clustered around the optimal service levels, the more economically efficient things become. So, the total cost of the system can be reduced by *improving* road segments that fall below the least cost LOS or by *downgrading* segments that have an LOS above the optimum. If all miles in a traffic band were at the optimal level, the model would show that *no improvements* were warranted.

In the county road network, mileages in each traffic band fall into a wide range of LOS categories. The majority of miles fall in or near the optimal but each traffic band in *Table 7-1* still contains many miles that could be upgraded or downgraded to reduce total cost. Segments in the level-of-service categories most distant from the least-cost level should have higher priority for upgrade/downgrade than those in closer ones because the per VMT savings of doing so will be higher. Examination of the table from that perspective indicates that the traffic range with the largest room for improvement would be the one from 80 to 175 vehicles per day, since the majority of its mileage falls 4 to 5 levels below the optimum. The tables show that there are about 7000 miles of gravel road in that range that merit upgrade – and doing so would reduce the per-VMT cost on them from about $1.75 to $1.50, saving around 25 cents per each mile of travel thereafter. At an average 115 vpd, this would reduce society's total cost of travel by $0.25 x 115 x 365 = ~$10,500 per mile per year. Improving 100 miles to the least-cost LOS would save $1,050,000 per year in total economic cost.

7b-3 Level of Service / Design aid implications of the UCT results

If one merges the traffic bands having a common least cost LOS and then enumerates the characteristics of that roadway type, the result is remarkably similar to the design guidelines that were discussed in the first two chapters of this report. *[Refer to Table 7-4 of the Supplement]*.

Selected data used to define the LOS categories at the outset of the study were brought into Table 7-4, along with information from the base, speed and UCT tables. The author's conclusion is that this approach can directly link design guidelines to the overall economics of the transportation system. This could be of use in future efforts to define design aids to be recommended for county routes.

The biggest unanticipated result of preparing and reviewing the UCT table was that the Optimal Levels-of Service tabulation, *Table 7-4*, seems to recommend constructing hard surfacing, (rock base with seal-coat or ACC type top layer), on roads with traffic between 78 and 580 vehicles per day. This runs counter to historical design preferences, which have tended to keep roads below 175 vpd granular surfaced while electing to grade and pave those over with traffic counts over 175 vpd. The explanation is probably that, for both practical (seal coat roads require much more frequent renewals) and political (the public likes pavement better than hard surfacing) reasons, counties have tended to stay away from hard surface type improvements.

> **Special caveat:**
> The model's indication that hard surfacing would be an optimal choice for road designs in the 78 to 580 vpd range DOES NOT mean that it is saying that past choices were wrong. It must be remembered that the model identifies what would be optimal at current cost levels. The ratios between road, vehicle, and human resource costs have not be constant, so there have been times in the past when selecting gravel or pavement over hard surface designs was the right thing to do. Traffic levels on many roads have also turned out higher or lower than was foreseen at the time of construction. And, when one plans to improve a road, it's necessary to build it superior to what current conditions require – so that it won't become obsolete too soon. The model merely reveals that, given the current costs of the items it takes into account, hard surface appears to provide a least cost solution in that 60 to 800 vpd range of traffic volumes.

To explore the difference between conventional practice and the TCT model, the following table compares current road class mileages with the configuration that would exist if all miles fell into the optimal levels-of-service for each traffic band:

Figure 7-6 (approximate numbers)

Road Type	Existing miles	TCT least cost mileages	Net difference
Earth	5324	2483	-2841
Gravel	67577	60645	-6982
Hard surfaced	1258	21377	+20119
2 lane paved	15620	5133	-10487
3/4 lane paved	22	140	+118

A major reason that the TCT model tends to favor hard surface improvements is that the model includes the cost of invested capital as an element of the UCT. There aren't enough annual VMTs per mile below 600 vpd to permit pavement to enjoy as low of a unit cost as that of the hard surface option because of its higher cost of capital. The cost figures used for both paved roads and their hard surface peers would need to be critically reviewed, however, before one could make a final judgment in this area. But the TCT methodology appears to provide a framework that could be used in performing such final analysis – for only the cost figures would be subject to possible revision – not the model itself.

7b-4 Cost category magnitudes & relationships

Having developed all UCT values with Fixed, Distance, or Travel time associations, an effort was made to investigate how the three types of cost relate to each other and affect the total UCT for each LOS/T-band combination. This was done by extracting two special tables,

- one showing the cost classes for each T-band of two levels of Service, *[Refer to Table 7-5a of the Supplement]*.
- another showing the cost class breakdown for all LOS categories within two traffic bands. *[Refer to Table 7-5b of the Supplement]*

The LOS settings were: #5-Gravel Level-2 and #10-Paved 2-line level-2. The traffic bands were #5: 35 to 52 vpd and #10: 260 to 390 vpd. Cells in-common between the two tables were shaded to make it easy to cross reference between them.

Table 7-5a shows how the fixed costs of the system, (mostly from the road network), dominate at low traffic levels but fade in importance as volumes increase. The constant, distance-based, (mostly vehicle), costs gradually become the majority component of the UCT as traffic counts increase, but then fade in importance at still higher levels where the time based costs come to predominate.

In *Table 7-5b*, it can be seen that all three cost types vary with each LOS within a single traffic band. The optimal service point arrives where the decreasing trend in fixed costs crosses the joint increasing trend of distance and travel time expense.

Table 7-5c, *[Refer to Table 7-5c in the Supplement]*, shows the percentage breakdown of cost types for LOS 10 and T-band 10, which is an average combination. It indicates that road network, vehicle, and human resource costs are the dominant factors in the economy of the system. Accidents are the fourth most important item, with all the others, (economic, business, social, environmental, and offsets), playing only minor roles.

7b-5 Data confidence and accuracy analysis

Since the authority of findings derived from the TCT model depends on the credibility of the cost data from which the UCT figures were computed, it's appropriate to ask, "How reliable and credible was the source data used in this research project?" Because the data was obtained from so many sources and much of that was based on other, prior sources, it wasn't possible to specifically determine soundness or range of error. Alternately, the author reexamined all source information at the end of the project and, half formally / half subjectively, estimated whether

a) one could have confidence that the final UCT figures where at the right order of magnitude
b) what range of error might exist.

The method by which these twin determinations were made was recorded in *Tables 7-6*. *[Refer to Table 7-6 of the Supplement]*.

As can be seen in the left hand section of the table, the author estimated the degree of confidence that could be placed in each set of source information being accurate -- using a scale of 1 to 100, where 1 = no confidence and 100 = absolute confidence. Greatest confidence existed in the road data, so it was given a rating of 95. The confidence in the accuracy of the cost offset figures was much lower, so they were given a rating of 60. Similar confidence factors were set for all major source data and then a weighted average was computed. The final confidence 'rating' came out at 91.8, which was high enough to suggest that the final UCT figures were at the right order of magnitude and were credible enough to permit drawing conclusions from them.

In the sister table, in the right hand part of *Table 7-6*, the author estimated the range of uncertainty that the final results inherited from the inputs. Because of road network, vehicle, and accident costs could be computed from source data and then independently validated by comparing the results to other sources, the author felt that their uncertainty was fairly low.   The development of human resource costs involved making more assumptions, so it was treated as having greater uncertainty.   The rest of the factors all had relatively high uncertainty.   However, when a weighted average range of error was computed, it came out at plus or minus 6.6 percent, which again suggested sufficient credibility existed in the model to permit drawing results out of it.

While these methods of assessing input data and model validity aren't formal proofs, they support placing a reasonable degree of confidence in the findings.

7c. Identification, selection, and prioritization of improvements

In Section 7b-2.2, it was noted that the UCT table shows where road and bridge network upgrades cost reduce the total cost of transportation. This section looks at the issue of identifying and selecting upgrade candidates to fill that need. It will also examine how the cost of making the improvements affects the merits of doing so.

Special caveat:

This section will be looking at how improvements to the ROAD NETWORK can help reduce the total cost of transportation. It should be duly noted that TCT does not consider this to be the ONLY way that such costs can be reduced.   But it is the only method available to the administrators and engineers of the road agencies in charge of the network. The other cost saving options lie with the private sector or with governmental rules on speed, vehicle sizes and weights, driver licensing, and road taxation.

7c-1 Determination of potential UCT savings

The first step in formally identifying upgrade (or downgrade) candidates is to develop a clear picture of the per VMT savings available. To that end, Table 7-7a-1 *[See Table 7-7a-1 of the Supplement]* was created. It shows, using the 14 LOS by 19 T-band table format established by the physical model, how many dollars per vehicle mile of travel, $/VMT, could be saved by upgrading a section of road from its current LOS to the least cost LOS of the relevant traffic band. This was done by subtracting the least VMT cost for each T-band from the per VMT cost in each level of service. When the least cost is subtracted from itself, in the optimal LOS category, the potential savings figure is zero. For all other levels of service, the result is a positive value showing what could be saved by converting from the current LOS to the optimal LOS. Such savings reflect the relative changes in fixed, distance, and time based costs that would result.

Examination of the table shows that savings for optimizing miles that lie in LOS categories near the least-cost LOS are small, while upgrades/downgrades of more distant LOS categories can producer large per-VMT economies. In Traffic band 5, the optimal LOS is #6-Gravel (Level 3). Upgrading a section of road from LOS #5 to LOS #6 will reduce total costs by just 5.1 cents per VMT. But upgrading a segment of LOS #1 roadway in the same T-band could save $2.76 per VMT.

7c-2 Cost of upgrading / downgrading from one LOS to another

Before formal analysis can begin, it’s necessary to know what it will cost to make each type of improvement. Once this information is known, one can compare potential savings to the costs of achieving them and use the results to evaluate degree of need and set priorities. To assist this effort, *Table 7-7a* was set up to indicate what it would cost to upgrade, or downgrade, a mile of road from any LOS to any other specific LOS. *[Refer to Table 7-7a of the Supplement]* The way that this was done has already been described in Chapter 6. A key feature of this table is that its columns fall into the same format as the T-band columns of the Upgrade/Downgrade savings table. So, if the least cost LOS in a traffic band, such as #5, in LOS #6, one can link column six of the improvement cost table to that T-band. This establishes, for each LOS, what it will cost to achieve the savings if service is upgraded to the least cost level.

It's important to note that the cost figures contained in *Table 7-7a* represent INCREMENTAL costs of improvement. This is because the cost to periodically restore the current level of service back to new condition has already been incorporated into the UCT figures. Since that amount of capital has been accounted for, the cost of improvement table only identifies how much ADDITIONAL capital will be needed if one is to upgrade to a higher LOS. For example, LOS 4 is estimated to have a capital value of $101,691 per mile, while LOS 6 has one of $145,145, (difference: $43,354). But the cost to upgrade from Level 4 to 6 will have an incremental cost of $94,299 – because part of LOS 4's value will be destroyed and have to be replaced as construction progresses.

7c-3 Determination of ratio of potential Savings to Cost of improvement

Once both the per-VMT cost savings and the cost of improvement are know, the ratio between the two can be computed and used to judge whether or not a particular upgrade (or downgrade) is warranted or not.

Example: In Traffic Band #5, upgrading from LOS #4 (Gravel Level 1) to LOS#6 (the optimum: Gravel Level 3), is projected to save $0.161 per VMT at an incremental cost of $94,299 per mile. Since the average vpd level for that T-band is 43.7, the annual savings would be:

1.0 mi x 43.7 vpd x 365 days/year x $0.161/VMT = $2,568.03 per year

The cost, per mile, to attain this savings would be $94,299. If one computes the 20 year present worth of the savings (using an interest rate of 8.0 APR), the result is:

9.81 (PW factor) x $2,568.03 = $25,213.30.

Since that is only 26.7% of the cost, it indicates that making the upgrade would not be justified, since the present worth of the savings falls short of recouping the cost to obtain them.

The total amount that can be saved with a LOS change is computed using the following formula:

[Vehicles/day] x [1 mile] x [365 days/year] x [$Savings/VMT] x [PW $\text{factor}_{20\text{years}}$]

The Savings to Cost Ratio, or SCR, of a LOS change is :

[PW_{20}value of savings] divided by [Cost of making the improvement]

7c-4 Savings to Cost ratio analysis

Savings to Cost Ratios (SCRs) were computed for all 266 LOS/T-band combinations in the model. The results were then placed in a new table. *[See Table 7-7b of the Supplement]*. Inspection of the data indicates that SCRs are relatively low for LOS categories near the optimum and are higher for more distance ones. This fits with common sense: there is less to gain in improving a road that's near optimum than improving one that is substantially inferior.

To help make the SCR results easier to view, the LOS/T-band cells were grouped and color coded, with back-ground shading, as follows:

- SERVICE ADEQUATE BAND:
  Contains those cells having Savings to Cost Rations of 1.00 or less -- highlighted in Yellow. All road segments in this categories are so close to providing optimal service that it wouldn't pay to improve them.
- UPGRADE JUSTIFIED BAND:
  Contains cells that a) fell below the optimal LOS in their traffic band and b) had a savings-to-cost ratio, SCR, of between 1.001 and 5.00 -- highlighted in Green. Road segments in these cells merit upgrades because the twenty year present worth of the potential per-VMT savings exceeds the cost of improvement.
- UPGRADE URGENT BAND:
  Contains cells that a) fell below the optimal LOS in their traffic band and b) had an SCR greater than 5.00 -- highlighted in Orange. Segments within this group have such a high Savings to Cost potential that they should be given priority over the UPGRADE JUSTIFIED group.
- SERVICE SUPERIOR BAND:
  This classification was applied to all LOS categories that fell above the optimal level within their traffic bands. These cells were highlighted in Blue. Road segments in this group are built and maintained to standards that exceed what's needed for current traffic levels.

All of the optimal levels of service fell withing within the Service Adequate grouping. Graphically, this group appears on the chart as a diagonal yellow band, starting out in the lower LOS categories of the lowest traffic band, then angling upwards across the chart to end up in the top

LOS groups of the highest traffic range. Along the way, it tends to have a 'depth' of between two and five LOS categories in each T-band.

The Savings to Cost ratio table, *Table 7-7b*, shows that there is a substantial range of LOS/T-band combinations that provide Adequate service for the traffic level experienced. In TCT terms this means that although their collective total cost of transportation is higher than would be the case if they were all at the optimal level, the cost of upgrading them exceeds the potential savings. Mileages in these categories should, therefore, be maintained as is. Road segments within the LOS/T-band combinations below the Service Adequate band, in the Upgrade Justified & Urgent groups, do merit improvement and can be prioritized by their savings to cost ratios. Route miles lying above the Service Adequate band, in the Service Superior range, exhibit a per-VMT cost higher than optimal because they do not carry enough traffic to dilute the network operations, depreciation, and cost of capital expenses to a sufficiently low level. Some of these roads might be candidates for service downgrades, but others are only temporarily overbuilt --since traffic growth will soon result in them becoming a lot closer to optimal. Some represent routes that have been bypassed, which reduced traffic counts, shifting the miles into lower traffic bands where the optimal level was lower.

7c-5 System evaluation using Savings to Cost ratio groups

Once service level groupings were identified, via the Savings to Cost Ratio table, it became possible to use that information to analyze the actual service adequacy of Iowa's county road network. This was done to ascertain the utility of TCT methodology and to see what insights could be gleaned in regard to the county network.

The service evaluation was done by superimposing the color coded groupings from the SCR table (*Table 7-7b*) onto the original LOS/T-band mileages table (*Table 7-1*). This resulted in a new table, *[See Table 7-8 of the Supplement]*, that shows existing where system mileages fall within the four service level groups identified in the previous section. Examination of the County Service Adequacy Analysis table shows that the majority of the system miles fall into the Service Adequate category. There are Upgrade Justified miles in each traffic band, but Upgrade Urgent miles are quite sparse. There are also quite a few miles in Service Superior categories, with the majority lying in LOS levels 10 & 11, (Paved Levels 2 & 3), of traffic bands 7 through 9, (78 to 260 vpd.) These total to around 2400 miles.

As with *Table 7-1*, the heavy (purple on color printouts) lines on the LOS Adequacy Analysis table enclose the LOS/T-band combinations most representative of past road network improvement decision making. These groupings fit quite well with the Service Adequate band of *Table 7-8* but there are some LOS settings in Traffic bands 7,8, and 9, (78 TO 260 vpd) that lie outside that range. However, under-improved mileages in T-bands 8 and 9 just about balance the overbuilt mileages in the same column, so the overall discrepancy is actually not all that great on a statewide basis.

The primary conclusion to be drawn from the Service Adequacy Analysis is that the counties have actually done a good job of meeting the public's needs. The majority of the system mileage falls into the Service Adequate category and there does not appear to be an excessive amount of unmet needs or overbuilt routes. The county road network, as it exists today, is about right for the traffic it carries; TCT analysis shows that the majority of its miles are economically justified. To more precisely define what this means, a special summary table was developed to classify and total the miles of each LOS that fell into the four service groupings: Service Superior, Service Adequate, Upgrade Justified, and Upgrade Urgent. *[See Table 7-9 of the Supplement]*. The results were as follows.

Of the 89,780 miles in the county network:

- 3013 miles (3.36%) fall into the Superior category
- 84516 miles (94,14%) are Service Adequate
- 2196 miles (2.45%) merit Upgrade Justified status
- 54 miles (0.06%) are in Upgrade Urgent condition.

Overall, these figures suggest that the county road system is well done.

7c-6 Conclusions regard upgrade identification and prioritization

The tables and analysis of Section 7c show that TCT methods can be used to both identify what portions of the transportation system are adequate and which would yield overall savings if improved. When the potential savings are compared to the costs of making improvements, it becomes possible to identify what LOS/T-band combinations offer the greatest return, and the Savings to Cost ratios help in the setting of priorities.

An important aspect of the TCT approach is that the setting aside of enough money to periodically rebuild a roadway typical of a particular level-of service is built into the Unit Cost of Transportation figures. The cost of improvement figures express what it will cost to change to the optimal level of service. This means that TCT gives first priority to maintaining what should exist and expresses capital improvement needs as the amount needed to rise to a higher level of service without cannibalizing other parts of the network. In short, TCT figures factors in replacement capital separate from upgrade capital.

In analyzing the merits of potential improvements, this report has opted to follow an implicit rule that if a road is upgraded, it should be improved to the optimal level. But there is nothing that requires that things be done that way. One might also want to examine the merits of other approaches, such as only upgrading to the point of being within the Service Adequate band or upgrading beyond optimum to allow for future traffic growth. The TCT model of this research effort could facilitate those types of investigations – but those avenues were not been pursued in this study.

The Section 7c analysis operates at the system level and does not identify or prioritize individual road segments. As such, it's more suited to be a long term system adequacy and upgrade strategy selection tool, rather than something to help pick specific projects.

7d Comparison of Existing, Optimal, and Adequate service levels – Iowa County Roads

With the system cost, adequacy, and improvement analysis tools defined, it became possible to explore some interesting questions:

- How do Existing, Optimal, and Adequate service levels compare to each other?
- What are the actual total costs of the transportation system?
- How much money should road agencies spend to operate and maintain the system?
- What are the total capital improvement needs to be met?

Examination of these issues helped with assessing the value and utility of the TCT concept and the spreadsheet / database model.

7d-1 Determination and comparison of alternate systems

As previously noted, the size and configuration of the transportation system was modeled by recording how many miles of road fall into each of the 266 LOS/T-band combinations available in the base table (see *Table 7-1*).

7d-1.1 Existing Configuration

The existing network, being the result of many different decisions made over a long span of time, exhibits a dispersed pattern of level of service versus traffic volumes. As a result, it is somewhat economically inefficient. Many route miles fall into non-optimal combinations. Because these sub-optimal match-ups between service and traffic show higher unit costs of transportation, UCT, than their optimal siblings, overall total-system cost is susceptible to being reduced. This can be accomplished by upgrading or downgrading roads that fall into the non-optimal combinations.

7d-1.2 Optimal Configuration

The optimal system would be one where every system mile fell precisely into the least cost level of service, LOS, for the traffic level it serves. If this situation could be achieved, there would be only one cell containing mileage in each traffic band and all others would be empty. Then the entire system could be said to be operating at least possible cost. Of course, in practice it's not actually possible to attain the optimum, so it represents a goal to head towards, not a destination that can be reached.

7d-1.3 Adequate Configuration

Because it's not realistic to think in terms of a fully optimized system, the author developed the concept of an ADEQUATE system as being one that is so close to being optimal that there would be nothing to be gained from further improvement. This would be a system where all mileages fell within the Service Adequate band of *Table 7-8*. To explore what this type of system might look like, one was artificially created by taking all miles that fell outside of the Service Adequate zone and moving them into the optimal level of service category of each traffic range. The result is a LOS/T-band mileage table where all system miles are within the Adequate grouping and the other three groupings are empty. *[Refer to*

Table 7-10 of the Supplement]. This configuration lies between Existing and Optimal and might be achievable if sufficient capital for improvements were available. Its Total Cost of Transportation would be less than that of the Existing System but still not as low as the Optimal. (Special note: for this exercise, the author included the downgrading of Service Superior miles to optimum as well as improving those meriting upgrades. Another approach, perhaps more representative of likely real-world practice, would be to assume that Service Superior sections would just be left as-is.)

7d-1 Comparison of alternate configurations

The following mini-table illustrates the similarities and differences of the three configurations:

Figure 7-7

LOS	Description	Existing	Adequate	Optimal
14	Paved - 4 lane - divided	1	45	15
13	Paved - 4 lane	1	0	0
12	Paved - 3 lane	21	6	125
11	Paved - 2 lane - Level 3	5411	4000	5134
10	Paved - 2 lane - Level 2	9739	8494	0
9	Paved - 2 lane - Level 1	470	335	0
8	Hard Surface - Level 2	235	4605	21377
7	Hard Surface - Level 1	1022	755	0
6	Gravel - Level 3	4453	4887	24013
5	Gravel - Level 2	32250	31795	29288
4	Gravel - Level 1	30854	29830	7344
3	Earth 2 lane	4242	4009	0
2	Earth 1 lane	317	295	2483
1	Unimproved	765	724	0
		89780	89780	89780

The Adequate system is not much different from the Existing except that it would tend to have about 4000 more miles of Hard Surfacing. The Optimal, being an ideal, would have a substantially more compact configuration.

7d-2 Total cost comparisons

Once the system configurations were set up, each one's Total Cost of Transportation could be computed as follows:

- For each LOS/T-band combination, multiply [Miles] x [vpd] x [UCT]
- Sum the LOS/T-band TCT's in each column

- Sum the TCT sub-totals into the final total.

This was done for each of the three alternates. Results, in TCT dollars per day, are presented in three tables. *[See Tables 7-11a, 7-11b, and &-11c of the Supplement].* The data from each table was then consolidated in a special tabulation to permit comparison and analysis. *[Refer to Table 7-12 of the Supplement]*.

The top three rows of Table 7-12 present the Total Cost of Transportation, (Daily TCT), generated in each traffic band for each system configuration. The Existing system costs are always highest and those of the Optimal layout are the least. The fourth and fifth rows show the costs of the Adequate and Optimal networks as percentages of the Existing system amounts. Overall, the theoretical Adequate network would operate 1.93% cheaper than the Existing and the Optimal figures establish that the maximum possible cost reduction is 5.15%. Despite the small percentages, the total annual savings potential is significant. The sixth and seventh rows show the dollars per day that could be saved. These figures were computed by subtracting the Adequate or Optimal costs from those of the Existing setup. For the Adequate system, the total daily reduction in TCT is $341,494, or $124.65 million per year. The maximum amount that could be potentially saved per year is $332.66 million – as shown in the Optimal System grand total.

These figures illustrate that, economically-speaking, road improvements reduce society's total transportation expense. This implies that failure to maintain the system and/or failure to upgrade it when warranted would have the opposite effect.

7d-3 Overall capital improvement needs

Given that Section 7d-2 suggests that there are economic cost savings to be achieved through the making of road improvements, the next task is to determine how much capital is needed and where it should be allocated. To investigate, LOS/T-band mileages of the Existing System (See Table 7-1) were each multiplied times their associated costs of upgrading them to the nearest optimal service level. The results were placed in a Cost of Upgrades table, *[Refer to Table 7-13a of the Supplement]*. This table was given the Service status color coding from Table 7-7b to show how the upgrade needs fall within the range of LOS and Traffic Band combinations.

The data from Table 7-13a was summed into Service Superior, Service Adequate, Upgrade Justified and Upgrade Urgent categories for each LOS. <u>*[Refer to Table 7-13b of the Supplement]*</u>. Then the four groupings were totaled to obtain final capital improvement revenue needs. The grand total from this exercise is exceptionally large: it indicates that to improve all roads to their Optimal service level would require about $7.5 billion dollars. This is far too large a figure to ever actually get funded – but, luckily, most of it isn't actually needed. The amounts in the Service Adequate zone represent projects that would have a Savings to Cost ratio of less than one, which means that the expenditures wouldn't be warranted. This leaves the totals of the other three columns, which are much smaller:

- $335 million to downgrade overbuilt facilities
- $392 million to improve Upgrade Justified segments
- $ 12 million to make Upgrade Urgent improvements

These items total to $739 million, which work out to an average need of $7.465 million per county. If a somewhat massive 'catchup' effort were undertaken to actually attain a fully adequate system, it would require an extra $750,000 per year per county for 10 years – a significant increase over current spending. That increase is not so large, relative to existing budgets, as to be impossible – although it must be conceded that it's unlikely that Iowa's citizens would ever be willing to impose the requisite tax rates upon themselves.

Still, there would be merit in trying to make citizens and leaders aware that such spending would have the benefit of reducing total system costs by $124.65 million per year. The 20 year present worth of such savings would be in the range of $1,222.82 million, resulting in an overall Savings to Cost ratio, SCR, of $1222.82 / $739 = 1.65. The savings would result from having more direct routes between origins and destinations, increased average speeds of travel, and reduced accident frequencies.

In actual practice, one would not spend much on downgrading Service Superior facilities: If traffic counts are declining, it's easiest just to let the affected routes slowly deteriorate. If traffic is increasing, the route will eventually stop getting classified as exceeding current needs. So the system's real capital need would be the $404 million for Upgrades. That amount, if spread over 10 years would come out to around $410,000 per county per year. Again, it shows that upgrading the county road system to reduce total costs is something that could be accomplished. Society has the financial capacity to do it – but perhaps not the inclination.

7d-4 Operation and maintenance needs

Regardless of whether anything actually gets done or note, it would be instructive to determine what it would cost to operate and maintain the road network that resulted from such efforts. Since such cost figures were individually determined and converted to per-VMT form for inclusion in the final UCT values, the TCT model permits making such calculations.

Within the overall determination of per-VMT costs, those arising from the existence and operation of the road network were classified into the following groups: Administration, Engineering, Operations, Maintenance, Repairs, and Depreciation. The first two are self explanatory. The others were given somewhat specialized definitions for TCT purposes, so they are list below:

- **Operations** costs are those expenditures that are needed to make a facility useable without affecting its overall condition. Examples would be electricity to operate lights or signals, plowing of snow off roads in the winter, and cutting brush out of roadsides
- **Maintenance** includes those activities performed to prevent an asset from deteriorating. Examples: sealing bridge decks, re-striping pavements, sealing cracks, or reseeding bare spots to prevent erosion.
- **Repairs** are actions taken to restore the serviceability of a facility that suffers from partial deterioration. Examples: Replacing a deteriorated stringer in a bridge, patching potholes, or fixing a bent sign post.
- **Depreciation** covers the cost of things that restore a facility back to or near its original condition. This includes reconstruction, overlays that extend service life, and driving all new piling under a bridge abutment.

The author chose to label these items as AEOMRD expenses, using the first letter from each key word. Since all six items were separately developed in the UCT derivation, they were summed to give a per-VMT cost of operating the road network – by LOS and Traffic bands. These values were multiplied times miles and vpd to get daily costs, then by 365 to get annual costs. The results of these computations, expressed as $Millions per year are presented in three tables: for Existing, Optimal, and Adequate system configurations. *[Refer to Tables 7-14a, b, and c of the Supplement].*

When all the individual AEOMRD totals were summed, it showed that the cost of running the Existing system would be around $428 million per year.   (That figure is consistent with County Engineer Annual report, Farm-to-Market fund, and Federal aid data for 1998)   The estimated cost of running an optimal system would be $526 million per year and that of an Adequate network would be $437 million per year. These results suggest that upgrading a network to reduce its Total Cost will result in a need to spend more money be on AEOMRD expenses thereafter. This is because the higher levels of service cost more to provide. To reduce total costs, society will end up spending more on the road network component of the overall system.

7e Total System Costs

In addition to analyzing the status and costs of the system from the road network perspective, TCT methods permit looking at the overall system and all cost sources. This gives a greater understanding the proportions and interrelationships of the components.

To build a total cost worksheet, the UCT sub-totals for Roads & Bridges, Vehicles, Human Resources, Accidents, Business & Economic factors, Social / Environmental costs, and Cost offsets, were all multiplied by miles and vpd to compute daily costs for each Traffic band. The T-band column totals were then multiplied by 365 days/ year and reduced to $Millions per year format. The totals for each cost source were then tallied in a summary table and final T-band totals were obtained. *[Refer to Table 7-15 of the Supplement]*.   The results are best expressed in the form of $Dollars of cost per day per mile for each traffic band. These values range from $23 in the lowest band to $11,477 in the highest.   But if converted to cost per vpd, the figures start out with a high of $5.75 in the lowest band then decline to $1.05 in the highest volume band.

Special note:

The Road network figures in this section do not include the amount spent on upgrading the system. Analysis of source data for the road network indicates that this amount was in the range of $24 - $25 million per year in the time frame during which this report was being prepared. As noted before, such funds represent the incremental costs of upgrading the system to higher levels. The cost of restoring existing facilities back to new condition from time to time is included in the UCT figures.

As a final step the individual T-band totals for each cost source were totaled to get system wide totals. These, in turn, were summed to compute the final Total Cost of Transportation for the Existing system. *[Refer to Table 7-16 of the Supplement]*. This final summary indicates that the total annual expense of owning, operating, and using the county road system in Iowa is $6,459 billion. Vehicle costs make up the largest part of this: the $3,403 billion spent to own and use them makes up 52.7% of the total. The next largest cost is that of human resources: at $1,706 billion the paid time consumed while traveling represents 26.4%. So the top two items constitute 79.1% of the total picture.

Road network costs come in at $1,237 billion per year or 19.2 percent. Of this, only $428 million (6.6%) represents funds received and spent by county road departments. Another $16 million per year is spent on auxiliary items by other parties. But the biggest component of the overall road and bridge cost is the $794 million per year cost of invested capital. This latter item is substantial and interesting. If roads were run as a private business, this figure would become incorporated into the fees that the owners would charge users – in order to obtain a return on their invested capital. to get back from their enterprise. Instead, society has elected not to charge end users for this cost. With regard to the county system, this amounts to a hidden subsidy to system users in the amount of $0.17 cents per mile of travel. So if someone drives 15,000 miles per year in the county roads, they underpay the cost of using that system by $2550.

Even though the cost of capital is not recouped from transportation users, it nevertheless is a real cost that is indirectly born by all citizens. It represents the return that could have been earned on the amounts that have been invested in the road network -- if they had instead been invested in other productive assets. At the personal level it’s not a large amount, only $265 per capita per year, but it adds up to a large number on a statewide basis.

Accident costs come in at $224.5 million per year, working out to $616,731 per day – illustrating how much room for improvement still exists with regard to this aspect of transportation. The last significant item is the Cost Offsets figure. At -$119 million per year, this 1.8% item represents cost savings enjoyed elsewhere in the economy due to the present of the transportation system. The Business & Economic and Social / Environmental cost elements turned out essentially negligible for county road traffic levels.

The ratio between the cash cost of the [Vehicles + Human Resources + Accidents – Offsets items] and the [AEOMRD cost of the road system] is 11.7 to 1. This helps one comprehend how a small change in road costs can result in much larger changes in total system costs, since the two cost groups tend to move in opposite directions.

7f. TCT costs and revenue needs

Previous analysis in this report suggested that the county road network in Iowa is not only generally adequate but also economically justified. Addition sections have shown that, in general, it is necessary to make capital investments in and increase operating expenditures on the system in order to minimize the Total Cost of Transportation. Yet county road expenditures are today and for years, have been attacked as wasteful. Therefore, it seemed appropriate to conduct some study of the revenue vs. cost situation to see what could be learned.

To this end, another special table was created. *[Refer to Table 7-17 of the Supplement]*. To start, ongoing AEOMRD and capital improvement costs for the road network were distributed and totaled for all Traffic bands – in $Millions per year. Then, using an estimated road use taxes revenue rate of 4.5144 cents per VMT, which included both state and federal road taxes, the annual RUTF revenue generated per mile of road in each T-band was estimated. The results ranged from $66 per mile per year in the lowest band up to $180,719 in the highest. Then, since property and other local taxes have been running around $100 million per year, (per 1998 County Engineers Annual Report Summary), that sum was divided by system mileage to get a per mile per year figure of $1448. The two revenue figures were then summed and converted to $Millions per year format.

The annual cost in each traffic band was then subtracted from the estimated revenue to compute a net figure for each one. The results of this are presented in the Total Revenue less Expenses line of *Table 7-17*. As can be seen, the first 11 traffic bands, (those with 0 through 580 vpd),show net losses – meaning that, given current road and property taxes, they generate less revenue than they cost to operate. In the remaining bands, #12 to #19, (those with 580 to 14620 vpd), brought in more revenue than needed to cover their expenses. Overall, then system did not generate enough revenue to pay for its cost operation, falling short by $115 million. This shortfall was made up mostly by funds generated on the primary highway system.

Before proceeding with the rest of this section, it should be noted that the fact that the system did not generate enough revenue to pay its full cost does not negate the fact that it is economically justified. It reveals, instead, that society has been unwilling to set road use and property tax rates at a high enough level to make self financing possible.

Given that society is reluctant to pay the full price of the system, one alternative would be to close down a sufficient number of miles so that the system would become self financing at current taxing rates. To that end, a special backwards summation was run: starting at T-band 19, the net revenue less expense figures were added together in reverse order to find the point were costs finally exceeded revenues. It turned out that self financing can be achieved only for the top 12,133 miles of the system. Thus, if this approach were to be implemented, the remaining 77,646 miles would need to be closed. That is no doubt too drastic of a solution to be acceptable, even though it would free up $115 million per year to be spent by the DOT and/or cities. It would be quite economically costly, too: most of the travel would still need to take place but would become much harder, circuitous, and time consuming.

Another approach would be for the state to simply dictate to counties that $115 million per year of their current RUTF would be cut. Starting from the lowest traffic band and working upwards, this would require closing about 36,300 miles of system, (40%), The roughly 270 million annual VMT currently generated on the roads to be closed, which works out to an average of 20 trips per day, would not, however, entirely disappear. What would happen is this:

- To move between the same set of origins and destinations via the reduced system, travelers would have to take longer, more circuitous routes on the remaining roads.
- Depending on location, this could increase trip length anywhere from two times to six times the old distance.
- The increased distance and time of travel would raise the perceived price of such movements, resulting in some reduction in the number of trips.
- But, the probable result would be that total VMTs on the remaining system would be incremented by more than the amount lost off the eliminated sections.

- The net result would be a reduction in the AEOMRD & Upgrade costs of the system while the Total Cost of Transportation would be increased.

The option of raising RUTF and property tax rates to a level that would permit the entire county network to become self financing might also be proposed. To see what would be required, the author made the following assumptions:

a) first, that RUTF revenues would be increased by 8% -- half by raising the fuel tax by 2 cents per gallon and half by charging more for vehicle registrations
b) that rural property owners would then agree to be taxed at whatever rate it took to make up the difference between county system RUTF revenue and system costs.
c) The 8% increase would make an additional $80 million per year of overall RUTF available and free up the $115 currently going to the county system. After subtracting the counties' incremental share of the RUTF, that would leave about $180 million per year additional for State and City roads.

After some experimentation, it was found that this approach would work only if property tax levies for roads were increased by 77%. (Even then, the top 5,273 miles would be carrying the rest of the system). This approach would have a very hard time getting approved, too.

The ultimate solution will, of necessity, fall somewhere in between the two extremes of system closure vs. tax rate increase.

7g County level analysis

Although it is useful to conduct statewide system evaluations, as has been done in Sections 7a through 7f, there are also times when one would want to focus on a single, specific county. It turns out that the database/spreadsheet model used in this study can facilitate that with simple filtering. One can extract the mileages of a single county, distribute them into the appropriate LOS/T-band cells and then conduct all of the evaluations previously described in the full system analysis sections.

To test this flexibility and scalability, a mileage model was extracted and set up for all 99 counties. The Service Superior, Service Adequate, Upgrade Justified, and Upgrade Urgent groupings were color coded to help visually classify how well each county's network fits its current transportation needs. The results show interesting variety: some counties have very tightly clustered patterns while others are quite dispersed. Some seem to have relatively high amounts of Service Superior roadways; others seem to have relatively high improvement needs. Others seem to have almost a perfect fit between need and service levels. [The results of this exercise are available in *Appendix 1 of the Supplement, identified as Table set 7-18]*.

As was done for the full system, (in Table 7-9) the mileages for each county were summed to obtain Service Superior, Service Adequate, Upgrade justified and Upgrade Urgent categories for the fourteen levels of service. This information, along with total miles in each LOS, and in each major LOS classification is shown to the right of the LOS/T-band tabulations. Finally, the four adequacy group columns were totaled and converted to percent-of-system to facilitate county to county comparisons.

The county comparison percentages were collected into a summary worksheet so that the results could be sorted and analyzed. This permitted ranking counties according to three major service adequacy conditions. A description of each condition and associated findings follow:

7g-1 Overall service level adequacy

The objective of this analysis was to identify which counties come closest to fully meeting or exceeding all traffic needs vs. those who appear to be behind. The ranking was established by combining the Service Superior and the Service Adequate miles of each county and then sorting the results in descending order. The resultant findings were:

- Two counties, Humboldt and Worth, are at the point where their systems do not need any further improvements, (at this time).
- About half the counties are at 98% or higher.
- 85 percent of the counties have 95% adequate systems or better.
- Only one county, Linn, falls below 90%. The author believes that this is because they have been very conservative about making service upgrades, preferring instead to bring all of their bridges into top condition.

These results reinforce the earlier findings, suggested in the statewide system analysis, that counties have done a very good job of building a system to fit actual traffic needs.

7g-2 Service Superior rankings

This review was done to identify which counties have the most miles of Service Superior status roadways and, conversely, to find which have the least. The analysis was performed by sorting the list of counties by Service Superior percentages, in descending order. The results were as follows:

- The overall statewide average was that 3.36% of system miles manifest levels of service that exceed current needs.
- Sixty counties had Service Superior percentages within plus or minus two percent of the statewide average.
- The top five counties were:
    - Greene – 13.38%
    - Polk – 12.11%
    - Worth – 10.81%
    - Kossuth – 10.10%
    - Osceola – 9.41%
- The counties with the least Service Superior miles were:
    - Chickasaw – 0.78%
    - Jefferson – 0.59%
    - Bremer – 0.58%
    - Madison – 0.53%
    - Tama – 0.52%

The counties with high percentages possess systems that can accommodate significant traffic growth without needing further improvement – but their systems will generate higher than needed Total costs until such increases are realized. The counties with the least percentages currently enjoy near minimum total costs – but would need to commence upgrading immediately if traffic volumes picked up. Overall, the best strategy would be for counties in both groups to move closer to the statewide average.

7g-3 Upgrades needed rankings

The final county level analysis was to find out which ones have the greatest current upgrade needs. This was accomplished by sorting the list of counties by their Upgrade Justified percentages.

- The statewide average was that 2.41% of all route miles need upgrades, (and 0.06% additional fall into the Urgent group.)
- As would be expected, the counties having the lowest overall adequacy percents show up as having the greatest percentages of upgrade eligible miles.
- The top five counties in this ranking are:
  - Linn – 11.14%
  - Johnson – 9.72%
  - Des Moines – 9.71%
  - Lee – 9.57%
  - Warren – 9.53%
- The counties with the least need for upgrades are:
  - Pocahontas – 0.14%
  - Greene – 0.10%
  - Ida – 0.06%
  - Humboldt – 0.00%
  - Worth – 0.00%

The counties exhibiting above average upgrade needs are some of the state's more urban and faster growing areas. The low needs tend to come from regions where population is rural and stable or declining.

Special Note:

In viewing and evaluating the county by county rankings, readers should keep in mind that the percentages show the magnitude but not the intensity of need. There are different levels of need, so one can have situations where two counties have the same percent of system in need, but the intensity of need will be greater in one of them. This factor is especially worth noting in regard to Greene and Linn Counties. Greene County registered as having the highest percent of system built in excess of current needs. An examination of their individual county tabulation shows that 83.1 miles in this grouping, (or 64%), is in LOS 11 / T-band 9, which is only one step above the Service Adequate zone. The SCR for that combination is 1.1, indicating that those roads are not overbuilt by much. For Linn, 89 of their 130.4 miles needing upgrade fall in LOS/T-band group that have SCRs between 1.2 and 2.2, with 43 miles at 1.6. While this still shows that upgrades are warranted, they are not in Urgent territory.

7h Segment level analysis

While the spreadsheet model permits both system-wide and county by county analysis, it falls short of full scalability because it cannot assist a user in evaluating individual road segments or finding the specific sections of road that fall into the Upgrade Urgent rankings. To investigate at that level of detail, one must turn to the database section of the model.

Since the goal of this project was to test TCT concepts at all levels of detail, an effort was made to perform the upgrade needs analysis to every single segment in the DOT's base record list. The procedure used was as follows:

- Using *Tables 7-7a-1*, Per VMT savings when current LOS is changed to optimal, and *7-7a*, Cost of changing from one LOS to another, where combined into a 266 record table containing key data regarding each LOS / T-band combination:
  - Traffic band
  - Current LOS
  - Optimal LOS for the T-band
  - Per VMT savings to change to optimal LOS
  - Cost of changing upgrading / downgrading to optimal LOS
- The new table was imported into the main TCT Access database to serve as source data for computational queries.
- Special queries were run to identify all segments where the current LOS is below the optimal level. (This focused the study on upgrade candidates only, and excluded evaluation of Service Superior segments)
- Each segment's specific AADT and length were used, along with the costs data table to compute a) the 20 year present worth of potential savings and b) the cost to make the upgrade.
- Those results were then used to compute an individual SCR for each segment.
- All segments with an SCR of 1.0 or less were then filtered out, leaving only those that truly merited upgrades. The final list was then sorted into SCR order, from least to greatest.

Table 7-20 *[Refer to Table 7-20 of the Supplement]* summarizes the results of the segment level analysis: It shows that 2335 miles of roadway have an SCR of at least 1.0. 1623 miles have SCR's of less than 2.0. 439 miles have SCRs between 2.0 and 3.0 and 151 fall between 3.0 and 4.0. Only 122 miles equal or exceed an SCR of 4.0. The cost to upgrade all eligible segments would be about $422 million.

Since funding levels of the recent past have permitted counties to spend about $25 million per year for upgrades, it's instructive to explore how much of the need could be satisfied in the next five years, (presuming no changes in funding levels). Over that time period, there would be $125 million available for improvements. In comparing this to the cost column of Table 7-20 we find that this would cover improving all roads having an SCR of about 2.5 and up: the $125 million falls $29 million short of being able to finance all projects with SCRs >= 2.0. This suggests that upgrade project candidates ought to exhibit an SCR of at least 2.5 to merit consideration right now. Note that if society doubled its commitment to upgrade work, by increasing available funding by $25 million per year, the resulting $250 million over five years would still fall well short of permitting all warranted upgrades to be built.

It should also be noted that, over a five year period, improvement needs would not remain static. Where traffic grows, additional segments would reach the point of having SCRs greater than 1.0, thereby renew the backlog. Conversely, if traffic counts declined, more segments would fall into the "Adequate" service range – resulting in reduced need for improvement. Also, as discussed in the TCT theory sections, the upgrades themselves will help to lower the perceived price of transportation, which will induce people to drive slightly more than they did before and thus help generate new upgrade candidates in the future.

Having concluded that current funding, roughly speaking, should permit upgrading all segments having an SCR of 2.5 or greater, the final task was to try to identify and list some specific segments. This was done by running a filter query to narrow the list down to just those that had the SCR > 4.0 and then printing them out county by county. This output is presented as *Table 7-21* and is contained in Appendix 2 of the Supplement. It lists all SCR > 4.0 segments found for each county. The columns in this table are as follows:

Figure 7-8

No.	Col. Title	What it shows	Comments
1	RdID	Location and ID of the road	The 11 character **CCTTTRRSSRR** RdID format breaks down as follows: CC = County number TTT = Township RR = Range SS = Section number RR = Road number within the section
2	SgmtLen	Length in Miles	
3	AADT	DOT estimated VPD – yearly avg.	1998 data
4	XstLOS	Existing level of service	As computed from road characteristics
5	TgtLOS	Target level of service	The UCT determined optimal LOS for the segment's traffic band.
6	VMT Savings	Amount per VMT to be saved if road is upgraded to Optimal LOS	Current UCT less optimal UCT – in $Dollars per VMT
7	20YrCstSavings	Estimated present worth of the VMT savings	For I = 8.0%, the PW of 20 years of savings comes out to be 9.81 x 1 year's savings
8	UpgradeCost	Cost per mile to upgrade from Existing to Targe LOS	Costs were taken from Table 7-7a
9	UpGrdAmt	Actual cost to upgrade this segment	Equals segment length x UpgradeCost
10	SCR	Savings to cost ratio	Item 7 divided by Item 9

After generating Table 7-21, the author looked up numerous individual segments in various counties to see if the results were consistent with the roads' character and location. In general, the model's output corresponded well with the author's knowledge of county roads.   But there were some segments in the Table 7-21 upgrade list that obviously should not have been. Most of these case can, however, be explained as arising from errors or mistakes in the base data. Note that not all 99 counties showed up in the tally: apparently some did not contain any segments with an SCR of 4 or greater.

It thus appears feasible to use TCT methods to help identify and prioritize individual road segment improvement needs. The TCT approach offers a new way to approach this task and merits favorable consideration as a supplemental method.

7i. Long term service level analysis

Although modeling and evaluation of the transportation system at a particular point in time produced interesting and useful results, the theory and model also needed to be able to handle how a system changes over time. So an exercise was performed to test how well TCT would perform such a task. This was done, first, by predicting how traffic growth would change the system over a five year interval and, second, by then modeling what effect five year's worth of service upgrades would have on the outcome.

7i-1 Modeling the county road network over time

The modeling work required working with both the database and spreadsheet sectors of the model:

- Starting in the database, five years of traffic growth was modeling by applying each road's growth rate to the traffic it carries.
- Using the formula $Traffic_{Year5} = Traffic_{Year0} \times (1+[Growth\ Rate / 100])^5$, an end of interval AADT figure was established for all segments.
- A special query was then run to determine what traffic band each segment would belong in at the end of the time period.
- Based on the T-band results, the optimal level of service was identified.
- Using the final LOS values versus those of Year Zero, it was possible to compute the present worth of potential savings, calculate the cost to upgrade, if appropriate, and figure a Savings to Cost ratio.
- At this point, EXCEL pivot tables were used to extract the results from the database and consolidate it in the standard 14 LOS x 19 Traffic bands format used throughout this project.
    - To model the system after five years of growth, the cross-tabulation was performed on Year$_{\underline{5}}$ traffic volumes combined with Year$_{\underline{0}}$ LOS assignments.

- To model the system after five years with improvements, the cross tabulation was performed on $\text{Year}_{\underline{5}}$ traffic combined with $\text{Year}_{\underline{5}}$ levels of service.

The data was then reviewed and analyzed in spreadsheet format, as described in the following sub-sections:

7i-1.1 Evaluation of 5 years traffic growth

The state of the system at the end of year five was collected and represented in a level of service versus traffic band mileage tally. *[Refer to Table 7-22a of the Supplement]*. Comparing this tabulation to the original system tally, in Table 7-1, one can see significant changes in VMT totals, both by level-of-service category and in each traffic band. Overall, total VMT was modeled as increasing by 12.45%, from 4588.5 to 5159.7 million VMT per year. This corresponds to system wide average growth rate of 2.37% per year.

To better understand what changes had taken place the Year Zero mileages in each LOS / T-band combination were subtracted from their equivalents in the Year Five table. This produced a net change table. *[Refer to Table 7-22b of the Supplement]*. It shows changes in every category, with some cells losing miles and others gaining them. Readers should note that, in the context of the TCT model, traffic growth manifests itself as a shift of mileage from lower traffic bands to higher ones but all mileage remains in the level of service category in which it started. This shows up in the table as follows: all net LOS mileage changes are zero while each traffic band experiences a net gain or loss.

The shifts that occurred within the county road system model were a bit abrupt, rather than smooth and uniform. For instance, the miles of Traffic band #4 seem to have jumped to Band #5 all together. A similar jump from Band #5 to #6 also occurred. The author believes that, in lower AADT ranges, this effect is due to the fact that DOT base record traffic counts are largely estimated values, which tend to be rounded to the nearest multiple of ten or twenty. But the effect is also present in two higher bands that would have a more even distribution of counts, so it may also be an inherent feature of system growth dynamics.

7i-1.2 Impact of 5 years' improvements

A new table was then formed to represent the system's status after fives years of traffic growth PLUS five years worth of improvements. *[Refer to Table 7-23a of the Supplement]*. For ease of computation and to stay consistent with previous sections, the author chose to presume that the current level of funding for upgrades, approximately $25 million per year, would continue through the entire five years. This would make a total of $125 million available which, as discussed in Section 7h, would permit completing all upgrades having a Savings to Cost Ratio of 2.5 and higher.

Comparison of this table with the 'Growth without improvement' data in *Table 7-22a*, reveals an outcome where traffic has been shifted to higher levels of service. In the right hand totals, one can see that this resulted in the VMT per mile per day column to increase for all but the lowest LOS categories. Since overall VMT remained the same between the two situations, the change can be characterized as a shift of miles to lower cost levels of service as traffic growth makes it appropriate.

The data in the Year Five worksheet was then subtracted from that in the Year Five + Improvements table to isolate and show the areas of net change. As can be seen from examination of the traffic bands, the addition of improvements manifests itself as follows:

- Mileages are subtracted from sub-optimal levels of service
- The miles in the Optimal level are increased by a like amount.

In this instance, the traffic band mileages remained unchanged while the level of service categories all saw net changes.

7i-1.3 Comparison of ending with starting conditions

Once the two sets of data had been prepared, a) Growth without upgrade and b) Growth plus improvements, the miles were multiplied times average vpd's and unit cost of transportation, UCT, values to compute daily Total Costs of Transportation for each one. These results were placed into two tables and summed to obtain system wide daily TCT's. *[Refer to Tables 7-24a and 7-24b of the Supplement]*.

The results of 7-24a and 7-24b were matched with similar figures for year zero, from Table 7-11a, to produce a final comparison and analysis grid. *[Refer to Table 7-24c of the Supplement]*. Year Zero occupies the first row, followed by the two sets of Year Five totals in lines 3 and 4. Inspection of the traffic bands indicates that growth results in a reduction of TCT in lower bands, due to a loss of traffic, and corresponding increases in the higher bands. And it can be send that the total cost at the end of the period is less with improvements applied than if no effort had been made to respond to the growth.

With growth but no improvements, the daily system TCT increases by 10.08%, from $17,696,299 to $19,479,664. The addition of improvements lower that latter figure by $98.078, or only by 1/18, but that still saves $35.8 million per year overall. So, if one attempts to save money by not making road improvements, other system costs will likely increase enough so that the final total will actually be higher than they would have been.

7i-2 Forecasting impacts of operating strategies

Given that Section 7i-1.3 suggests that the making of improvements is necessary if costs are to be maintained as low as possible, it seemed appropriate to explore what would happen if one neglected the system. This was done by assuming that the current $25 million per year for improvements would be reversed: that funding would be allowed to fall $25 million per year below what's required to maintain the existing system at a steady state condition level. (This would be a net reduction of spending by $50 million per year, or an 11% decrease from past practice.)

In actual practice, such a shortfall would result primarily in degradation of system quality: agencies would be force by law and public opinion to try to keep all existing levels of service the same but would not be able to prevent the facilities from deteriorating. Since the model used in this effort did not permit direct modeling of condition, the decline was simulated by moving 1% of the mileage in each Traffic band left to the next lower T-band within each level of service row. Rough calculation indicated that spending $25 million per year improved approximately ½% of the system miles per year. Because money to maintain a system affects more miles per year that dollars spent to upgrade do, the author elected to figure that the decline would occur at double the rate of improvements.

The findings from this exercise are presented in a summary table. *[Refer to Table 7-25 of the Supplement]*. It indicates that, (if the 1% LOS reduction is in any way valid at representing the results of under-investment), that letting the system decline actually increases the overall system costs.:

- **Year 5 – No improvements:** If no improvements are made, the annual amount spent on roads, (the AEOMRD figure), would be reduced by $25 million per year but system TCT would be $651 million higher than it was at the start of Year Zero.
- **Year 5 – With improvements:** If the improvements are made, there is no net savings in road expenditures but the TCT increase drops to $615 million – so the overall increment goes down by $36 million per year.
- **Year 5 – with disinvestment:** If the system is permitted to decline, $51 million per year could be shifted back for use on city and state roads, but the non-road resources consumed by transportation activity on the county system would increase by $707 million. The resulting net increase would be $656 million.

The Year Five option which expends the most dollars on the road network actually achieves the least system wide TCT. The option that spends the least, accomplishes the opposite effect.

7i-3 Section summary

TCT appears capable, both in theory and model, to represent and permit analysis of time related changes in the character of a transportation system. This type of inquiry requires more database preparations in advance, but both changes due to growth and those due to level of service changes can be incorporated into the same final table, providing a composite view of system dynamics.

There are a couple items that could perhaps be done to obtain more truly representative results, but they wouldn't be critical in most cases:

- It's possible that a road segment's rate of growth factor should be modified when it falls into a new traffic band or gets upgraded to a new level of service. For example, if traffic on a gravel route was increasing at 1.5% per year and the route was upgraded to Paved Level 2, the new surface might attract enough new users to boost future growth rates to 2% per year. The author found no authoritative information on this issue but believes it could affect long term results.

- The opening of new links and the closure of old ones changes both the total quantity and distribution of traffic in the system. So one might want to simulate change on a year by year basis, first deleting closed segments and estimating the disposition of their VMTs, the adding in new links and adjusting traffic as needed, then computing growth, then finishing with the application of improvements.

7j. Chapter 7 Summary and Conclusions

The goal of this chapter was to demonstrate the various types of inquiry and analysis that could potentially be handled with TCT methods and models. Secondarily, it sought to obtain answers and insights about Iowa's county road transportation system. This section summarizes what was learned and evaluates how well the TCT approach performed.

7j-1 TCT theory and model evaluation

The Total Cost of Transportation theory seemed able to serve as a framework in which all major topics and issues could be posed, dissected, and analyzed. Design guidelines, system adequacy, overall system costs, road network operation costs, revenues versus expenses issues, county by county, segment by segment, and time interval dynamics all seemed amenable to study with the concept. And, while Iowa's county road system was used as the test bed for evaluating all the above cited capabilities, there is no reason why the theory could not also be used to evaluate state highway issues, city streets, or even national networks.

The database and spreadsheet model proved highly flexible. System level analysis could be performed primarily with the spreadsheet portion while segment level investigations could be done via the database. The model was relatively easy to assemble and Section 7b-5 shows that if the four primary cost factors, (vehicles, human resources, roads & bridges, and accidents), can be ascertained with a reasonable degree of confidence, final results will have a strong weight of authority. Plus, the model can be considered a perpetually open system, receptive to continuous refinement as new knowledge about system costs and interrelationships becomes available.

Building the overall structure of multiple database tables, queries, and detailed spreadsheets required considerable effort and time. But, once established, they form a framework in which data can be updated and results renewed with little additional work.

Final conclusion:

Both the TCT theory and database/spreadsheet model have proved to be viable tools for transportation analysis and decision making.

7j-2 County road system findings

As has been noted several times, the data used to test theory and model was not completely current during the evaluation period – February 2002. Thus, it's not possible to draw any final conclusions from the findings derived from the testing work, even though the data was more than adequate for the 'proof of concept' effort.

Nonetheless, it seems safe to summarize the most reliable findings here, just to document what types of things may be determined via use of TCT methods:

- Past design and service level decisions have resulted in a system that consists primarily of earth and granular surfacing -- for traffic levels below 78 vehicles per day.
- Pavement is preferred for volumes in excess of 260 vpd.
- In the range between 78 and 260 vpd, opinion has been divided, with some parts paved and other sections remaining granular.
- Half of the transportation activity occurs in the top 7.8% of the system mileage, leaving the remaining VMTs spread very thinly across a large network of lower volume routes.
- Higher traffic volumes must be permitted to operate at higher speeds in order to be carried economically.
- Existing system mileage is fairly dispersed in terms of level-of-service vs. traffic levels, but does not appear to be significantly over or under built.
- Total system costs can be reduced by upgrading those parts of the system having LOS settings below the optimal level for their traffic load. It appears that this might cost as much as $404 million, but could help reduce **total** costs down by $125 million per year.
- Vehicles constitute about 51 percent of the total cost of transportation on the system, with roads and human resources both coming in at about 19 and 26 percent respectively. Accidents are just under 4% and all other cost items are quite small. (Although it should be remembered that the other items will become more significant in higher traffic volume situations.)
- Although the system is well balanced with traffic from a total cost point of view, current road tax rates are set too low for it to be self financing. As a result, a substantial quantity of revenue generated on the state system makes up the difference.
- Trying to remedy the revenue generation shortfall by system reduction or tax increment both call for such drastic changes that neither option is attractive.

- Current funding available for system upgrades appears sufficient to fund all projects with Saving to Cost ratios of 2.5 or greater over five years. This would result in the upgrading of about 500 miles, or 0.55% of the system.
- Traffic growth results in an increased total cost of transportation.   Road improvements help keep the cost minimized.

7j-3 Potential applications

As will be discussed in Chapter 9, TCT has potential to be used in a variety of public policy, transportation system evaluation, planning, design, and management activities. It can be used to select design aids, conduct total or partial system analysis, help with selecting specific segments for improvement, and in comparing different strategies over time.

The following bulleted list suggests some practical applications where the TCT concept might be employed, if further refined:

- Selection of design aids for a road network
- Choosing between alternatives for a future project
- Evaluation and documentation of system adequacy
- Selection and prioritization of capital improvement candidates
- Anticipation of future ongoing and capital expenditure budget needs

Chapter 8

SINGLE PROJECT TCT MODELS AND ANALYSIS

8. TCT modeling and analysis of specific project issues

One of the objectives identified in Chapter Two was to determine if a scalable concept could be developed: one that could be used for both system-level and project level analysis. Chapter Seven demonstrated how TCT principles could be applied to perform system-level investigations. This Chapter will examine how well suited the concept is for project level investigations. Five separate design / planning scenarios will be explored.

The five test scenarios cover a range of decision making situations that confront road agencies and design professionals in the ordinary course of project development. Each one is slightly different, but all embody the need to make choices between alternatives. The situations featured in the following sections are:

- Determining whether or not to build a new road.
- Determining the degree to which a road should be upgraded.
- Deciding whether or not to replace an aging bridge.
- Choosing between alternate alignments.
- Evaluating whether or not a design exception is justified

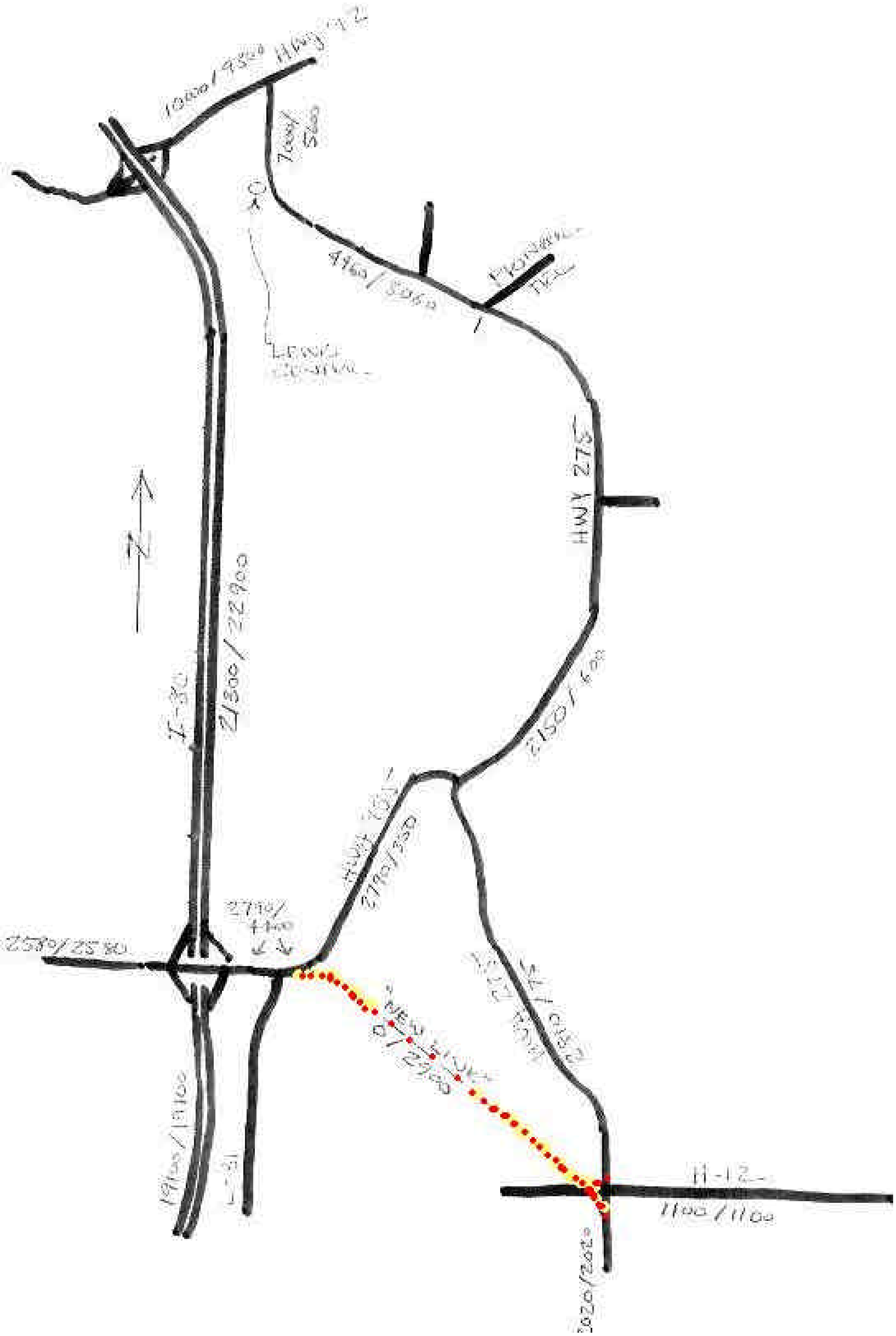
TCT methods and models will be applied to each case to test the concept's applicability and ease of use.

8a. Evaluation of proposed of new link

The first case examines the issue of whether or not a new link should be added into an existing road network: should the system expanded? In this type of situation, the question is whether expending public capital to enhance road-user convenience is appropriate and cost effective.

8a-1. Scenario

The situation to be explored in this section draws upon a real world example. In western Iowa, along the border of Mills and Pottawattamie Counties, there exists a route configuration that is inherently inefficient. Traffic between northwestern Mills County and the Omaha-Council Bluffs area travels to a junction with State Highway 935, at which point the drivers must a) backtrack about two miles in order to access Interstate 80 for the remainder of the trip or, b) continue on Hwy 275, on a shorter but slower route, to Council Bluffs, then connect to I-80 via Highway 92. Figure 8-1 shows the layout and connections of the routes involved.



The map shows the routes, the location of a possible new link, and indicates current and estimated future traffic levels, (in a "before/after" format), expressed as vehicles per day.

If the new link were constructed, a substantial portion of the traffic now using Highway 275 from H-12 north to Highway 92 would divert to follow the shortened path to I-80. So, the question is whether or not the capital cost of building such a link would be justified by any resulting travel distance and travel time savings.

This cannot be done by analysis of the proposed new corridor solely by itself, since adding it in will provoke a significant change in travel patterns on several other routes. Also, even if the new connection is built, it won't be possible to shut down any old ones, so the overall social investment in the fixed based would be substantially increased.

8a-2. Modeling proposed improvements

Evaluation of this situation via TCT can be done via a before and after comparison of TCT costs for all affected routes to determine net savings. That result can then be compared to the additional capital that must be added to the system to effect the changes. Table 8-1 presents the format of the before / after spreadsheet model set up to facilitate the analysis. The sequence of work was as follows:

1. Affected routes were cataloged as a list of segments having unique level-of –service (LOS) and traffic count ranges.
2. Before / after miles, LOS categories, traffic volumes, and traffic bands were determined for each segment.
3. Before and after vehicle miles of travel per day, VMT/day, were computed for each segment.
4. Based upon LOS and Traffic-bands, the before and after Unit Costs of Transportation, $Dollars per VMT, were extracted from Chapter 7's Total UCT table.
5. The before and after VMTs were multiplied times their associated UCT values to compute daily TCTs.
6. Subtraction of the After-TCT from the Before-TCT produced a daily savings amount that was converted to its twenty year present worth equivalent.

7. The final 20 Year PW savings amount was then divided by estimated cost to determine a Savings to Cost ratio for the proposed improvements.

Although the list of steps appears a bit long, as enumerated above, the actual process of setting up a spreadsheet based analysis template did not prove difficult. Initial preparations took the most time: preparing the map, estimating before and after traffic patterns, and assigning initial / final LOS categories to each route. Once that work was complete, it took about 30 minutes to set up the spreadsheet, import UCT and cost of improvement data from the Chapter 7 worksheets, and set up formulas to make the necessary calculations.

8a-3. Analysis & discussion

The statistics of adding in a new link came out as follows:

- The size of the affected road network would have to be increased by 2.60 miles, at a cost of $1,835,686. This 14.6 percent increase in miles would boost total route miles to 20.35.
- Because the new link would reduce total trip distance for a substantial number of travelers, the overall daily vehicle miles of travel within all affected routes would decrease by 2.6 percent – from 155,490 to 151,454 per day. This illustrates a typical reason for building new roads: doing so can decrease the total of amount of travel.
- Changes in traffic volumes would require that certain road segments, like Hwy 275 north of H-12 be assigned to new traffic bands, changing their UCT costs per VMT.
- The changes in LOS and traffic would result in increased TCTs in some parts of the network, such as I-80 and the new link, while leading to decreased TCTs on the other sections. The overall result would be a 3.3 percent reduction in total costs – indicating that travel distance and time savings would outweigh the fixed-cost increases resulting from the addition of 2.6 miles of new roadway into the system.
- The final, twenty year value of the savings computes to be $17,818,301. Since the estimated cost of the project would be $1,835,686, this indicates that the Savings to Cost Ratio, SCR, of the proposal would be 9.7 to 1.

Some advantages of using the TCT approach to evaluate this situation are that the spreadsheet and map would provide a good framework for guiding discussion of the matter, the format and calculations could be understand by members of the general public, and "what-if-it-turns-out-this-other-way" questions would be easy to handle. Disadvantages include the fact that it takes extra up-front effort to prepare the worksheet and citizens might feel intimidated by all the numbers and suspect that the model had been "set-up" by its author to justify a predetermined outcome.

An interesting aspect of this test case is that the routes potentially affected by the proposed link are administered by three different road agencies. So, in addition to being used to determine project feasibility, the TCT methods might also assist in defining which agencies should be in charge of which segments afterwards, and even help determine appropriate adjustments in AEOMRD funding for each one.

8b. Evaluation of alternative levels of improvement

The second test case concerns a question that arises whenever a road, or bridge, is under consideration for upgrades: what level of improvement would be best? As discussed in Chapter 2, design aids tend to define a range of options, while tools like the paving points analysis and design exceptions studies help justify the selected option – but aren't oriented to identifying the best option.

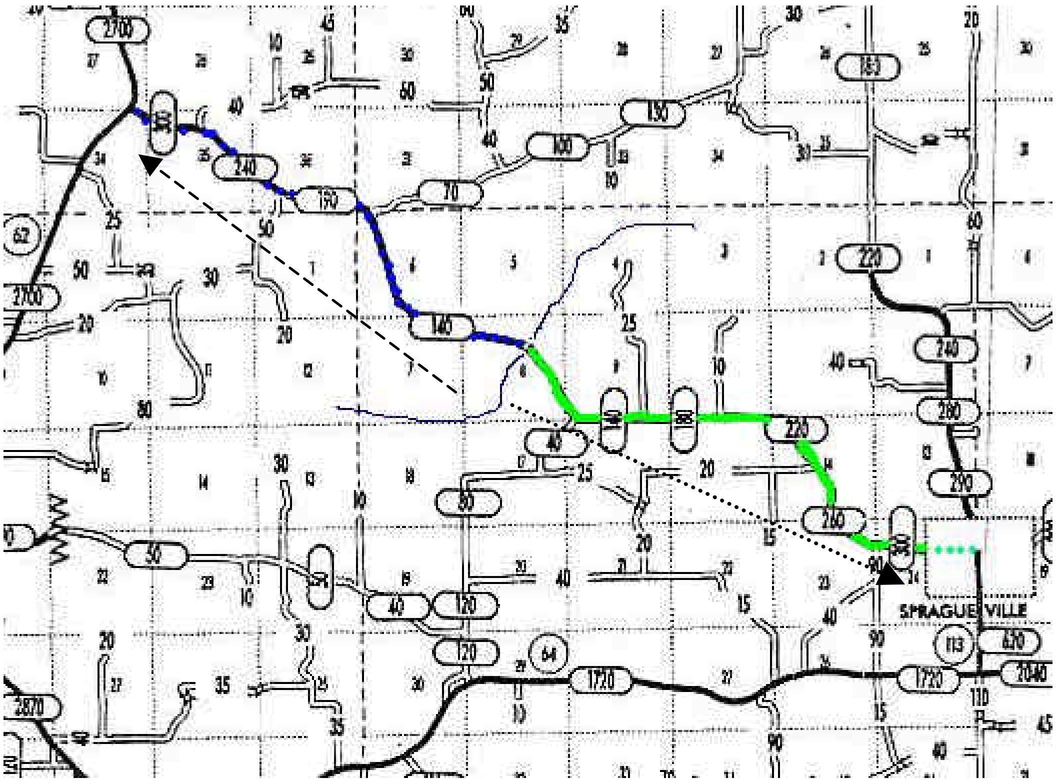
This scenario will, therefore, attempt to employ TCT methods to find and recommend an "optimal" design level for upgrading a section of road. This will be done by computing Savings to Cost Ratios, SCRs, for all upgrade alternatives. The objective will be to determine what target Level of Service would be best suited to the traffic volumes carried on the route.

8b-1. Sample route

This example is based on the Iron Bridge Road, E23Y, route in Jackson County, Iowa, that helped precipitate this research project. As noted earlier, the road was ultimately re-graded and paved, so the outcome of this exercise will be academic. But it will suffice for exploring TCT's abilities.

The west five miles of the E23Y corridor was already paved. The question at hand was whether or not the east end should be upgraded to highest possible level, or only to the level used for the west section -- or somewhere in between. There was also considerable variation in traffic level along the length of the study zone, leading to the question of whether or not the entire length should be of a single design.

Figure 8-2



The west section is shown in blue. The east section is highlighted in green.

8b-2. Upgrade alternatives

Due to the existence of traffic levels ranging from 140 vpd, near the bridge, to 300 vpd near Spragueville, the author decided to create a model that would permit analyzing each traffic count level separately. The route was broken into five segments, as shown in Table 8-2. Since the existing roadway fell in the No. 5 level-of-service category, the UCT savings and cost of upgrading from LOS #5 to 6, 7, 8, 9, 10, or 11 was determined for each segment.

- The segment miles and traffic levels were used to compute VMT amounts for each one.
- The VMTs were then multiplied by the UCT savings achievable by upgrading to each of the six candidate levels of service.
- Savings to cost rations were then determined for all alternatives.

8b-3. Analysis and discussion

The results show that Section 1 did not appear to have enough traffic on it to justify any upgrade, but sections 2 through 5 all did. In those segments, LOS-8, (Hard Surface – Level 2) consistently displayed the highest SCR, but LOS-7, (Hard Surface – Level 1), was not very far behind.

If the decisions about this corridor remained to be made, a project engineer might use the results of the analysis to reason as follows: "Out of the 5.00 miles, 3.35 appear to warrant hard surfacing immediately. And, while the remaining 1.65 miles does not have enough traffic to justify improvement on its own, public expectations of route continuity demands that it be treated the same way. Plus, paving will cause some increase in usage so it's likely that traffic will pick up enough to validate the hard surface upon completion. Going beyond hard surfacing to a LOS with pavement and full shoulders does not appear justified at this time. Presuming traffic will grow at 2% per year, the AADT at the east end could approach 450 vpd, throwing it into LOS 11 – but that still wouldn't call for full paving. So it appears that the best choice will be LOS-8, but a LOS-7 would be a reasonable alternative if revenues fall short."

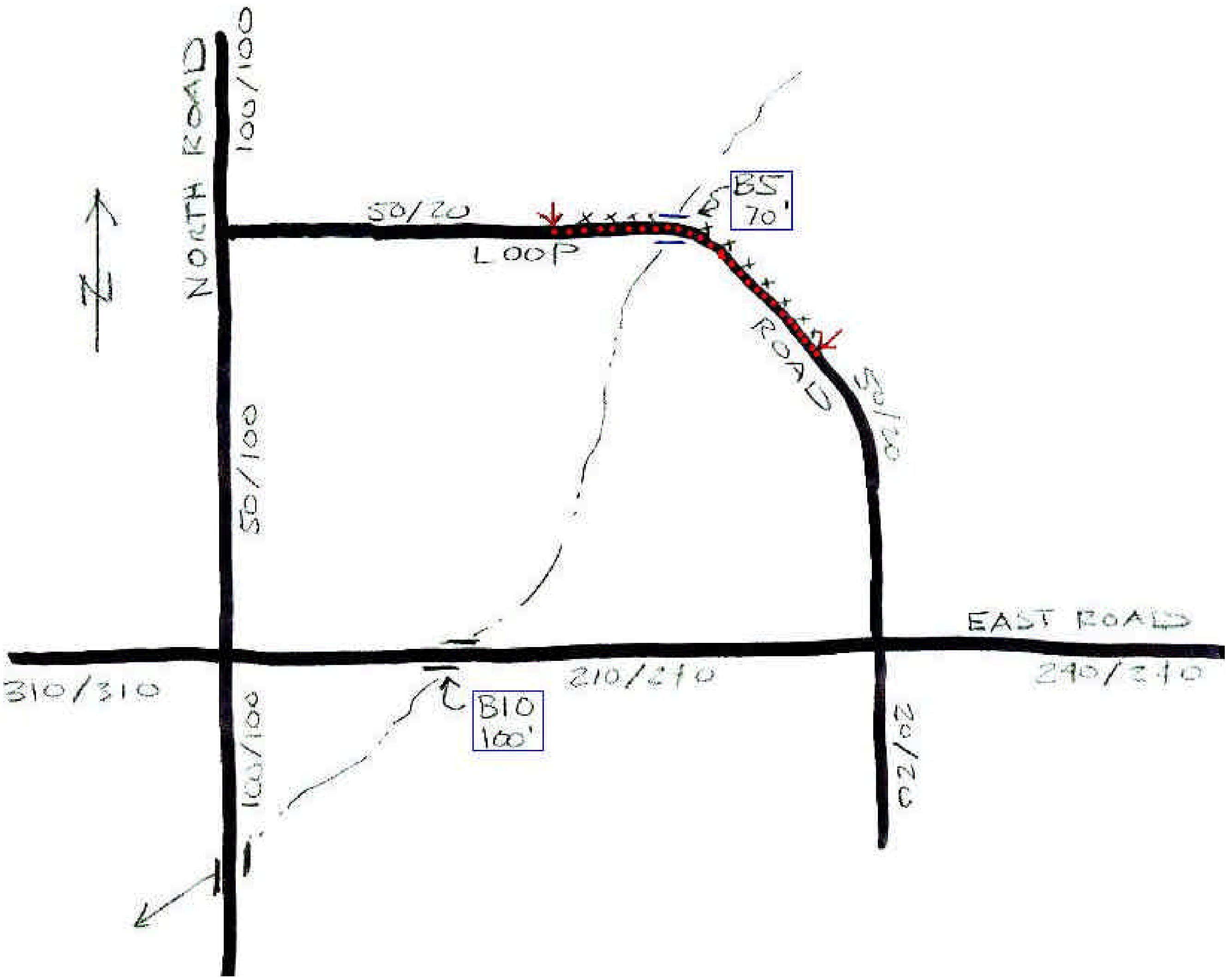
This example illustrates how a TCT review might assist a road designer in evaluating and choosing between available upgrade options. It also shows that TCT results, like those of any other decision analysis tool, need to be tempered by professional review and judgement.

8c. Determination of whether or not to replace bridge

Another issue county road managers often face is that of deciding whether or not to replace an old bridge when it has reached the end of its service life. This example will explore using TCT methods to analyze and compare two alternatives: a) to replace the old bridge with a new wider and longer structure or b) to remove the bridge permanently. (The option of just rehabilitating the existing bridge, while not included in this exercise, represents another choice that might need evaluation.)

8c-1. Scenario

The basis for this section's analysis is presented in Figure 8-3. This map shows a typical example of what one might find in some township in Iowa: a road that provides a shortcut has an old bridge. If replaced, the new structure will have to be lengthened and widened. If it isn't, traffic patterns will change on several routes.



The three (fictitious) roads involved are a) the East Road, a paved route, b) the North Road, gravel surfaced, and c) the Loop Road, also gravel surfaced. About 30 of the 50 vpd using the Loop Road are shortcut users. The remaining 20 vpd comes from dwellings and farm operations located along the Loop Road itself.

If the B5 bridge is replaced, it must be upgraded from 70 ft x 20 ft to 90 ft x 24 ft. If it is closed, the section of road highlighted in red, (and marked with 'x x x'), can be vacated and closed, too. This would decrease the total miles of the system but leave two dead end segments to contend with.   Traffic counts are shown for both options, in "bridge replaced / bridge closed" format.

8c-2. Modeling the options

Modeling and analyzing this scenario and associated options took the most work of any test case. Because system costs can be highly affected by even small changes in bridge length, the author decided to model road and structure costs separately. This required removing average bridge costs from the roadway UCT values prior to performing any calculations. It also necessitated treating bridges as special, very-high-cost levels-of-service.

The first step was to re-compute the roadway Unit Costs of Transportation figures pertinent to the situation. This was done as follows:

- The amount of UCT cost attributable to bridges in the standard UCT table was determined and then subtracted out of each LOS / Traffic-band's cost per VMT. (See Table 8-3a).
- This resulted in UCT values that reflected only roadway costs.

The second step was to compute cost figures specifically for bridges:

- $Dollar costs per foot per year were developed for both the B5 and B10 bridges. (See Table 8-3b).
- Bridge unit cost of transportation figures were developed for each structural alternate on a per-FOOT-of -vehicle travel basis. (See Table 8-3c)

Next, three separate tabulations were set up to model the three situations of the site:

a) The existing configuration with the old bridge still in service
b) The existing configuration with the old bridge replaced by a new one
c) A new configuration with the old bridge closed and part of the Loop Road vacated.

For each case, the estimated traffic was multiplied by the miles of route, (or feet of bridge), to determine activity level. Those figures were then multiplied by road or bridge unit costs of transportation to compute a TCT for each line item. The sum of all item TCTs produced a grand total to permit comparisons of the alternatives. (See Table 8-3d)

8c-3. Analysis and discussion

The final results indicate that if the bridge is closed, the total VMT of the system will increase. This would happen because drivers who had formerly taken the shortcut would be forced to take the longer route via the East and North roads. Thus even, though the cost of replacing the structure would have been avoided, the total cost of the system would be increased -- although not by very much.

The Savings to Cost ratio of replacing the bridge worked out to be only 0.9 if the new one had to be 90 feet long. A little what-if analysis showed that the SCR was greater than or equal to 1.0 for replacements lengths of 88 feet and less.

These results suggest that the best course of action is to close the old bridge. But the final decision would need to be tempered by additional knowledge: it the agency knew in advance that one or more operation on the Loop Road were about to close, it would be clear that the bridge was no longer worth keeping; on the other hand, if a new ethanol plant were about to open on the North Road, one could foresee an increase in Loop Road traffic that might justify replacing the structure after all.

The TCT model and analysis for this example became somewhat involved and, although it might be something that design professions might use in the office, it would be too complicated to use for any public presentations.

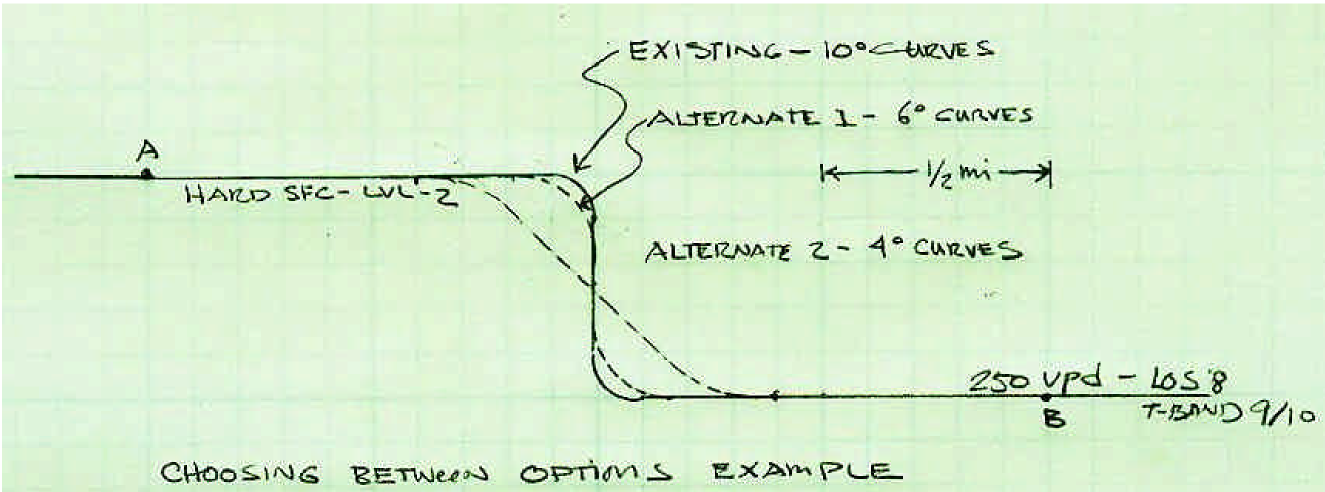
8d. Evaluation of alternate alignment options

Sometimes the question isn't about whether to build, close, or upgrade a route. The following example presents a case where the route is basically satisfactory but has a speed and safety deficiency at a spot location. The challenge in this circumstance is to determine whether or not the alignment of the route should be reworked to make the road more convenient and safer.

8d-1. Scenario

For this case, consider the situation where an otherwise straight road has a slight offset in alignment that requires vehicles to slow down and pass through two sharp, ninety degree curves.

As shown in Figure 8-4, two options have been identified. Alternate 1 would simply replace the existing 10 ° curves with 6 ° curves. Alternate 2 would change the offset connector from being perpendicular to the main route direction to a 45 ° crossover with 4 ° curves at each end. The question to be answered is: which of the two options is more appropriate. No. 1 wouldn't cost near as much as No. 2, but the degree of improvement would substantially less.



8d-2. Modeling the options

The physical and cost characteristics of the existing road and the two options were recorded in a small worksheet. (See Table 8-4)

- Route length reductions and their impact on total VMT were computed in the top section.
- Project quantities and costs were figured in the next two sections
- Savings in travel time costs, accident costs, and travel distance costs were computed and summed in the last section.

8d-3. Analysis and discussion

The results indicate that Alternate 2 is the better choice. Even though it would cost nearly double Alternate 1, the resulting Savings to Cost ratio of 2.6 is much superior to No. 1's 1.54. In either case, the increase in fixed costs would be offset by reductions in travel distance costs, travel time costs, and accident costs.

Although only two options were explored here, it wouldn't be hard to model a few more and seek to find the one with the optimal SCR. It would seem logical that the SCR might be improved still more if one flattened the crossover angle from 45^o to lower values. But at some point the increasing length of the project would tend to cause costs to begin increasing faster than savings. So there would be a 'optimal' choice that could be identified.

The model for this case was very easy to set up and use. The majority of the time required was spent on the task of computing curves and centerline distances. Once that information was ready the spreadsheet created in about ten minutes.

8e. Evaluation of TCT in design exception analysis

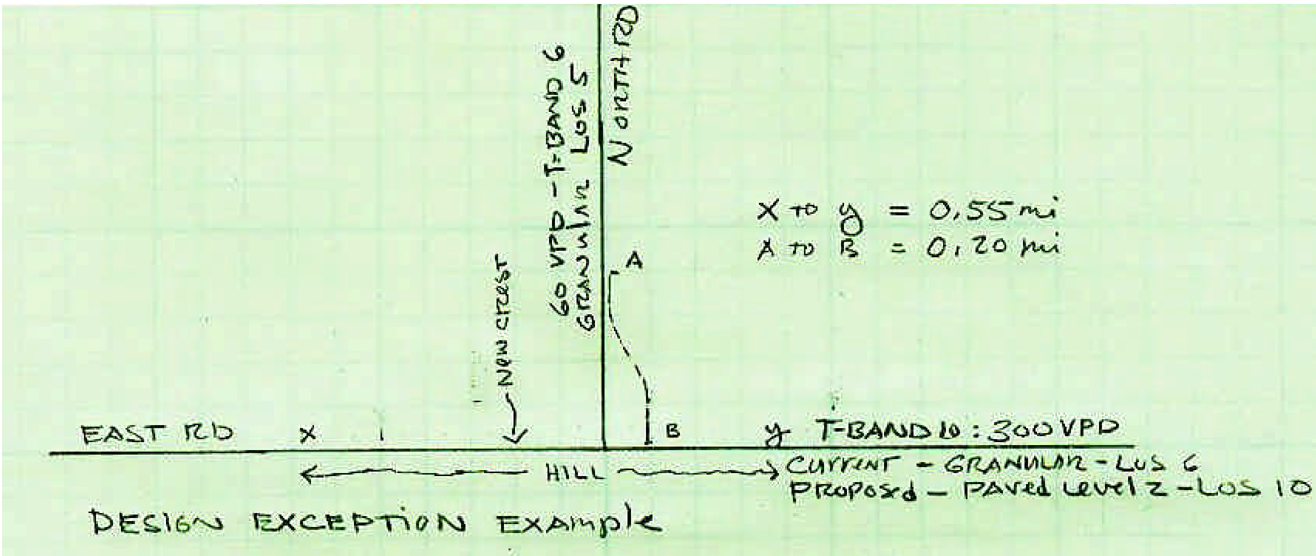
The final test case involves a design exception analysis situation. This one required comparing *cost differences* between options instead of total costs.

8e-1. Scenario

The example used for this case represents another situation commonly encountered during a road design effort: conditions at a spot location make it hard to stay completely in compliance with the design standards appropriate to the route and traffic levels.

As shown in Figure 8-5, this scenario involves a tee intersection perched at the crest of a hill. The road authority, expecting rapid traffic growth due to a new plant, has decided to re-grade and pave the main road. If design standards are followed exactly, the hill crest will have to be cut down by 8 feet, which will then require a lateral relocation of the side road. Because traffic on the side road is light, the agency would prefer to leave the intersection where it is and go with a shorter, sharper hill crest through that particular area. A design exception analysis is therefore needed to determine if the construction cost savings will be justified or not – in light of the fact that the lower level design zone will have a slightly higher potential for accident occurrences and traffic will not be able to maintain normal speed as they pass through this area.

Figure 8-5



8e-2. Modeling the options

The nature of this inquiry lent itself to use of differential quantity and cost analysis. Since the design change would affect only grading and ROW, other project costs were ignored. Similarly, since the overall travel distance would not be changed, only travel time and accident cost impacts were reviewed. (See Table 8-5)

- Detailed items and quantities were tabulated for the existing route and the two alternates.
- This data was used to calculate the net difference in construction cost between the full LOS-10 design level and the lesser one proposed in the design exception.
- Then the net additional savings in travel time and accident costs of the full LOS design over the lower one was computed
- Finally the Net extra savings was divided by the Net extra cost to determine the marginal Savings to Cost Ratio,

8e-3. Analysis and discussion

The analysis indicates that, while using the full LOS-10 design level through the hill zone would produce savings worth $28,466, it would cost an extra $70,308 to do so. This results in an SCR of only 0.40. Such a low savings to cost ratio indicates that use of a design exception in this area was justified and that the higher design level would not be justified in that spot location.

This model was relatively easy to set up and use. It appears to improve upon current design exception analysis in that it incorporates consideration of other factors, such as travel time impacts, as well as accident costs. It also takes the time value of money into account, making the comparison of savings to costs more realistic.

8f. Summary and conclusions

The test cases show that TCT methods can be used to analyze many typical issues that arise in the course of planning and designing road improvements. The author's conclusion is that TCT is indeed able to be used both at the system and at the project level, an attribute not matched many other methods.

Setting up the models for the test cases took more time than a busy professional would normally be able to devote to such tasks – but this was partly because they were being created for the very first time. Now that sample templates are available, future setups should go much faster. Perhaps enough so that TCT methods could become equally ranked with other tools at some future time.

Chapter 8 /Table 8-1

Road IDs, segment lengths, and level of service					Traffic volumes		VMT levels		Traffic bands		UCT amounts			TCT amounts		Upgrade Cost	
Sgmt#	Route	From/To	Length	LOS#	Before	After	Before	After	Before	After	Before	After	Change	Before	After	per mi	Total
I80.1	I-80	Hwy 370 to Hwy 92	5.2	15*	21,300	22,900	110,760	119,080	20	20	0.95	0.945	-0.005	105,222	112,531		
935.1	Hwy 935	I-80 to L-31	0.45	11	2,790	4,400	1,256	1,980	15	17	1.021	1.018	-0.003	1,282	2,016		
935.2	Hwy 935	L-31 to H-12 xtnsn	0.35	11	2,790	4,400	977	1,540	15	17	1.021	1.018	-0.003	997	1,568	379,404	132,791
935.3	Hwy 935	H-12xtnsn to Hwy 275	1.65	11	2,790	700	4,604	1,155	15	12	1.021	1.13	0.109	4,700	1,305		
275.1	Hwy 275	0.2 mi S of H-12 to H-12	0.2	9	2,020	2,020	404	404	15	15	1.086	1.086	0	439	439	425,952	85,190
275.2	Hwy 275	H-12 to Hwy 935	3	9	2,810	75	8,430	225	15	6	1.086	2.166	1.08	9,155	487		
275.3	Hwy 275	Hwy 936 to Pioneer Trail	3.8	9	2,150	600	8,170	2,280	15	12	1.086	1.151	0.065	8,873	2,624		
275.4	Hwy 275	Pioneer Trail to Lewis Central	1.5	10	4,460	3,060	6,690	4,590	17	16	1.051	1.054	0.003	7,031	4,838		
275.5	Hwy 275	Lewis Central to Hwy 92	0.6	13	7,000	5,600	4,200	3,360	18	17	0.986	0.999	0.013	4,141	3,357		
92.1	Hwy 92	Hwy 275 to I-80	1	13	10,000	9,300	10,000	9,300	19	18	0.99	0.986	-0.004	9,900	9,170		
H12.1	H-12 xtnsr	Hwy 275 to Hwy 935	2.6	11	0	2,900	0	7,540	0	15/16	0	1.118	1.118	0	8,430	622,194	1,617,704
			mi.		vpd	vpd	VMT/day	VMT/day			$/vmt	$/vmt	$/vmt	$/day	$/day	$/mi	Total $
		Before totals	17.75				155,490							151,740			
		After totals	20.35					151,454							146,764		
		Difference	2.6					-4036							-4,976		
		Percent change	14.60%					-2.60%							-3.30%		
															Savings		Cost
														20 PW	-17,818,301		1,835,686
															SCR	9.7	

Route	E23Y
Length	5 miles
Crnt LOS	5

Section	Traffic Volume	Traffic Band	Section Length	Best SCR
1	140	8	1.65	0.812
2	180	9-Aug	0.75	1.311
3	220	9	1.1	1.929
4	260	10-Sep	1	2.088
5	300	10	0.5	2.685
			5	1.575

Section 1	Traffic = 140				
New LOS	T-band 8 UCT	Upgrade Savings	20 Yr PW per mi.	Upgrade Cost/mi	SCR
11	1.777	-0.085	-42,610	563786	-0.08
10	1.645	0.047	23,561	427173	0.06
9	1.568	0.124	62,160	334076	0.19
8	1.44	0.252	126,325	155627	0.81
7	1.507	0.185	92,739	119769	0.77
6	1.567	0.125	62,661	86,737	0.72
5	1.692				

Section 2	Traffic = 180				
New LOS	T-band 8/9 UCT	Upgrade Savings	20 Yr PW per mi.	Upgrade Cost/mi	SCR
11	1.637	0.056	35,771	563786	0.06
10	1.535	0.158	101,511	427173	0.24
9	1.478	0.215	138,249	334076	0.41
8	**1.376**	**0.317**	**203,990**	**155627**	**1.31**
7	1.456	0.237	152,428	119769	1.27
6	1.533	0.16	102,800	86,737	1.19
5	1.665				

Section 3	Traffic = 220				
New LOS	T-band 9 UCT	Upgrade Savings	20 Yr PW per mi.	Upgrade Cost/mi	SCR
11	1.496	0.196	154,398	563786	0.27
10	1.424	0.268	211,115	427173	0.49
9	1.387	0.305	240,262	334076	0.72
8	**1.311**	**0.381**	**300,130**	**155627**	**1.93**
7	1.404	0.288	226,870	119769	1.89
6	1.498	0.194	152,822	86,737	1.76
5	1.638				

Section 4	Traffic = 260				
New LOS	T-band 9/10 UCT	Upgrade Savings	20 Yr PW per mi.	Upgrade Cost/mi	SCR
11	1.409	0.212	196,900	563786	0.35
10	1.356	0.265	246,241	427173	0.58
9	1.331	0.29	269,516	334076	0.81
8	**1.271**	**0.349**	**324,908**	**155627**	**2.09**
7	1.373	0.248	230,415	119769	1.92
6	1.476	0.145	134,525	86,737	1.55
5	1.62				

Section 5	Traffic = 300				
New LOS	T-band 10 UCT	Upgrade Savings	20 Yr PW per mi.	Upgrade Cost/mi	SCR
11	1.321	0.299	321,184	563786	0.57
10	1.287	0.333	357,707	427173	0.84
9	1.274	0.346	371,671	334076	1.11
8	**1.231**	**0.389**	**417,862**	**155627**	**2.69**
7	1.341	0.279	299,700	119769	2.5
6	1.453	0.167	179,391	86,737	2.07
5	1.602				

UCT of road network with bridge decks includec

	Traffic Band number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Min VPD	0	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9771
LOS	Max VPD	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9770	14620
#	ed Avg VPD	4	10.3	18.6	29.5	43.7	65.5	93.3	140.9	216.2	323.8	479.8	709.7	1057.9	1551.4	2327.5	3498.6	5290.3	7886.2	10967.6
14	Paved - 4 lar	71.302	27.69	15.334	9.668	6.527	4.354	3.057	2.024	1.319	0.881	0.594	0.402	0.27	0.184	0.123	0.082	0.054	0.036	0.026
13	Paved - 4 lar	60.371	23.445	12.983	8.186	5.526	3.687	2.588	1.714	1.117	0.746	0.503	0.34	0.228	0.156	0.104	0.069	0.046	0.031	0.022
12	Paved - 3 lar	44.535	17.295	9.577	6.039	4.076	2.72	1.909	1.264	0.824	0.55	0.371	0.251	0.168	0.115	0.077	0.051	0.034	0.023	0.016
11	Paved - 2 lar	31.826	12.36	6.844	4.315	2.913	1.944	1.364	0.904	0.589	0.393	0.265	0.179	0.12	0.082	0.055	0.036	0.024	0.016	0.012
10	Paved - 2 lar	24.917	9.676	5.358	3.379	2.281	1.522	1.068	0.707	0.461	0.308	0.208	0.14	0.094	0.064	0.043	0.028	0.019	0.013	0.009
9	Paved - 2 lar	20.306	7.886	4.367	2.753	1.859	1.24	0.871	0.576	0.376	0.251	0.169	0.114	0.077	0.052	0.035	0.023	0.015	0.01	0.007
8	Hard Surface	14.033	5.45	3.018	1.903	1.284	0.857	0.602	0.398	0.26	0.173	0.117	0.079	0.053	0.036	0.024	0.016	0.011	0.007	0.005
7	Hard Surface	11.208	4.353	2.41	1.52	1.026	0.684	0.481	0.318	0.207	0.138	0.093	0.063	0.042	0.029	0.019	0.013	0.008	0.006	0.004
6	Gravel - Leve	7.441	2.89	1.6	1.009	0.681	0.454	0.319	0.211	0.138	0.092	0.062	0.042	0.028	0.019	0.013	0.009	0.006	0.004	0.003
5	Gravel - Leve	6.009	2.333	1.292	0.815	0.55	0.367	0.258	0.171	0.111	0.074	0.05	0.034	0.023	0.015	0.01	0.007	0.005	0.003	0.002
4	Gravel - Leve	5.389	2.093	1.159	0.731	0.493	0.329	0.231	0.153	0.1	0.067	0.045	0.03	0.02	0.014	0.009	0.006	0.004	0.003	0.002
3	Earth 2 lane	2.927	1.137	0.629	0.397	0.268	0.179	0.125	0.083	0.054	0.036	0.024	0.016	0.011	0.008	0.005	0.003	0.002	0.001	0.001
2	Earth 1 lane	1.92	0.746	0.413	0.26	0.176	0.117	0.082	0.055	0.036	0.024	0.016	0.011	0.007	0.005	0.003	0.002	0.001	0.001	0.001
1	Unimproved	1.424	0.553	0.306	0.193	0.13	0.087	0.061	0.04	0.026	0.018	0.012	0.008	0.005	0.004	0.002	0.002	0.001	0.001	0.001

UCT of road network with bridge decks exclude

	Traffic Band number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Min VPD	0	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9771
LOS	Max VPD	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9770	14620
#	ed Avg VPD	4	10.3	18.6	29.5	43.7	65.5	93.3	140.9	216.2	323.8	479.8	709.7	1057.9	1551.4	2327.5	3498.6	5290.3	7886.2	10967.6
14	Paved - 4 lar	71.391	27.725	15.353	9.68	6.535	4.36	3.061	2.027	1.321	0.882	0.595	0.402	0.27	0.184	0.123	0.082	0.054	0.036	0.026
13	Paved - 4 lar	60.446	23.474	12.999	8.196	5.533	3.691	2.591	1.716	1.118	0.747	0.504	0.341	0.229	0.156	0.104	0.069	0.046	0.031	0.022
12	Paved - 3 lar	44.588	17.316	9.589	6.046	4.081	2.723	1.912	1.266	0.825	0.551	0.372	0.251	0.169	0.115	0.077	0.051	0.034	0.023	0.016
11	Paved - 2 lar	31.866	12.375	6.853	4.321	2.917	1.946	1.366	0.905	0.59	0.394	0.266	0.18	0.12	0.082	0.055	0.036	0.024	0.016	0.012
10	Paved - 2 lar	21.747	8.446	4.677	2.949	1.991	1.328	0.932	0.617	0.402	0.269	0.181	0.123	0.082	0.056	0.037	0.025	0.016	0.011	0.008
9	Paved - 2 lar	20.329	7.895	4.372	2.756	1.861	1.241	0.872	0.577	0.376	0.251	0.169	0.115	0.077	0.052	0.035	0.023	0.015	0.01	0.007
8	Hard Surface	14.044	5.454	3.02	1.904	1.286	0.858	0.602	0.399	0.26	0.173	0.117	0.079	0.053	0.036	0.024	0.016	0.011	0.007	0.005
7	Hard Surface	11.218	4.356	2.412	1.521	1.027	0.685	0.481	0.318	0.208	0.139	0.094	0.063	0.042	0.029	0.019	0.013	0.008	0.006	0.004
6	Gravel - Leve	7.449	2.893	1.602	1.01	0.682	0.455	0.319	0.211	0.138	0.092	0.062	0.042	0.028	0.019	0.013	0.009	0.006	0.004	0.003
5	Gravel - Leve	4.506	1.75	0.969	0.611	0.412	0.275	0.193	0.128	0.083	0.056	0.038	0.025	0.017	0.012	0.008	0.005	0.003	0.002	0.002
4	Gravel - Leve	5.395	2.095	1.16	0.731	0.494	0.329	0.231	0.153	0.1	0.067	0.045	0.03	0.02	0.014	0.009	0.006	0.004	0.003	0.002
3	Earth 2 lane	2.93	1.138	0.63	0.397	0.268	0.179	0.126	0.083	0.054	0.036	0.024	0.017	0.011	0.008	0.005	0.003	0.002	0.001	0.001
2	Earth 1 lane	1.922	0.747	0.413	0.261	0.176	0.117	0.082	0.055	0.036	0.024	0.016	0.011	0.007	0.005	0.003	0.002	0.001	0.001	0.001
1	Unimproved	1.425	0.554	0.307	0.193	0.13	0.087	0.061	0.04	0.026	0.018	0.012	0.008	0.005	0.004	0.002	0.002	0.001	0.001	0.001

CT figures when bridges are excluded.

	Traffic Band number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Min VPD	0	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9771
LOS	Max VPD	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9770	14620
#	ed Avg VPD	4	10.3	18.6	29.5	43.7	65.5	93.3	140.9	216.2	323.8	479.8	709.7	1057.9	1551.4	2327.5	3498.6	5290.3	7886.2	10967.6
10	Paved – 2 la	-3.169	-1.231	-0.682	-0.43	-0.29	-0.194	-0.136	-0.09	-0.059	-0.039	-0.026	-0.018	-0.012	-0.008	-0.005	-0.004	-0.002	-0.002	-0.001
5	Gravel – Lev	-1.503	-0.584	-0.323	-0.204	-0.138	-0.092	-0.064	-0.043	-0.028	-0.019	-0.013	-0.008	-0.006	-0.004	-0.003	-0.002	-0.001	-0.001	-0.001

Derivation of revised UCT (bridge costs omitted)

	Traffic Band number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Min VPD	0	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9771
LOS	Max VPD	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9770	14620
#	ed Avg VPD	**4**	**10.3**	**18.6**	**29.5**	**43.7**	**65.5**	**93.3**	**140.9**	**216.2**	**323.8**	**479.8**	**709.7**	**1057.9**	**1551.4**	**2327.5**	**3498.6**	**5290.3**	**7886.2**	**10967.6**
Total UCTs with bridge costs included																				
10	Paved - 2 la	$23.36	$9.69	$5.82	$4.04	$3.06	$2.38	$1.97	$1.65	$1.42	$1.29	$1.20	$1.14	$1.10	$1.07	$1.05	$1.05	$1.06	$1.08	$1.12
5	Gravel - Lev	$6.98	$3.64	$2.69	$2.26	$2.02	$1.85	$1.76	$1.69	$1.64	$1.60	$1.58	$1.57	$1.56	$1.56	$1.56	$1.58	$1.60	$1.66	$1.73
Total UCTs with bridge costs excluded																				
10	Paved - 2 la	$20.19	$8.46	$5.14	$3.61	$2.77	$2.18	$1.83	$1.56	$1.37	$1.25	$1.17	$1.12	$1.08	$1.06	$1.05	$1.05	$1.06	$1.08	$1.12
5	Gravel - Lev	$5.48	$3.06	$2.37	$2.06	$1.88	$1.76	$1.70	$1.65	$1.61	$1.58	$1.57	$1.56	$1.55	$1.55	$1.56	$1.58	$1.60	$1.66	$1.73

Bridge cost estimate basis

Bridge specific costs per foot per year				
No.	Item	10B-30	5B-20	5B-24N
1	Width	30	20	24
2	Unit cost	75	50	65
3	Cost per foot new	2250	1000	1560
4	Expected life	80	40	60
5	NBV vs. Original cost	0.75	0.2	1
6	Current cap. Value	1687.5	200	1560
6a	Cost of capital	135	16	124.8
7	Depreciation	28.125	25	26
8	Add for AEOMR	25%	25%	25%
9	Final cost/foot-year	35.15625	31.25	32.5

Derivation of bridge-as-LOS UCT per Vehicle foot of travel

	Traffic Band number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Min VPD	0	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9771
LOS	Max VPD	5	13	23	35	52	78	115	175	260	390	580	870	1300	1950	2920	4365	6530	9770	14620
#	ed Avg VPD	**4**	**10.3**	**18.6**	**29.5**	**43.7**	**65.5**	**93.3**	**140.9**	**216.2**	**323.8**	**479.8**	**709.7**	**1057.9**	**1551.4**	**2327.5**	**3498.6**	**5290.3**	**7886.2**	**10967.6**

Standard LOS UCT values per foot of travel

10B-30	Paved - 2 lar	0.00382	0.0016	0.00097	0.00068	0.00052	0.00041	0.00035	0.00029	0.00026	0.00024	0.00022	0.00021	0.00021	0.0002	0.0002	0.0002	0.0002	0.0002	0.00021
5B-24	Gravel - Leve	0.00104	0.00058	0.00045	0.00039	0.00036	0.00033	0.00032	0.00031	0.0003	0.0003	0.0003	0.00029	0.00029	0.00029	0.0003	0.0003	0.0003	0.00031	0.00033

Bridge specific UCT costs per foot of travel

10B-30	Paved - 2 lar	0.02408	0.00935	0.00518	0.00327	0.0022	0.00147	0.00103	0.00068	0.00045	0.0003	0.0002	0.00014	0.00009	0.00006	0.00004	0.00003	0.00002	0.00001	0.00001
5B-20	Gravel - Leve	0.0214	0.00831	0.0046	0.0029	0.00196	0.00131	0.00092	0.00061	0.0004	0.00026	0.00018	0.00012	0.00008	0.00006	0.00004	0.00002	0.00002	0.00001	0.00001
5B-24	Gravel - Leve	0.02226	0.00864	0.00479	0.00302	0.00204	0.00136	0.00095	0.00063	0.00041	0.00027	0.00019	0.00013	0.00008	0.00006	0.00004	0.00003	0.00002	0.00001	0.00001

Consolidated UCT

										10B-30										
10B-30	Paved - 2 lar	0.0279	0.01095	0.00615	0.00395	0.00273	0.00188	0.00138	0.00098	0.0007	0.00053	0.00042	0.00035	0.0003	0.00026	0.00024	0.00023	0.00022	0.00022	0.00022
5B-20	Gravel - Leve	0.02244	0.00889	0.00505	0.00329	0.00232	0.00164	0.00124	0.00092	0.0007	0.00056	0.00048	0.00042	0.00038	0.00035	0.00033	0.00032	0.00032	0.00032	0.00034
5B-24	Gravel - Leve	0.0233	0.00922	0.00524	0.00341	0.00239	0.00169	0.00128	0.00094	0.00072	0.00057	0.00048	0.00042	0.00038	0.00035	0.00033	0.00032	0.00032	0.00032	0.00034

5B-20	0.001978
5B-24	0.002043

Bridge replacement decision worksheet

Existing situation

Road IDs, segment lengths, and level of service			Segment			Traffic	Traffic			
Sgmt#	Route	From/To	Length	Units	LOS#	volume	Band	VMT/VFT	UCT	TCT
1	Loop Rd	North Road to bridge	2.05	mi.	5	50	6-May	102.5	1.8197	187
2a	Loop Rd	B5-20 bridge	**70**	**ft.**	**5**	**50**	**6-May**	**3500**	0.001978	7
2b	Loop Rd	B5-24 bridge	**0**	**ft.**	**5**	**0**	**6-May**	**0**		0
3	Loop Rd	Bridge to East Road	2.35	mi.	5	50	6-May	117.5	1.8197	214
4	East Rd	North Road to Loop Road	3	mi.	10	210	9	630	1.3657	860
4a	East Rd	B10-100 bridge	**100**	**ft.**	**10**	**210**	**9**	**21000**	0.000704	15
5	North Rd	East Road to Loop Road	2	mi.	5	50	6-May	100	1.8197	182
						vpd			$/VMT-VFT	$ per day
		Road totals	9.4					950		1443
		Bridge totals	170					24500		22
										1464

Existing situation + bridge replaced

Road IDs, segment lengths, and level of service			Segment			Traffic	Traffic			
Sgmt#	Route	From/To	Length	Units	LOS#	volume	Band	VMT/VFT	UCT	TCT
1	Loop Rd	North Road to bridge	2.05	mi.	5	50	6-May	102.5	1.8197	187
2a	Loop Rd	B5-20 bridge	**0**	**ft.**	**5**	**0**	**6-May**	**0**	0.001978	0
2b	Loop Rd	B5-24 bridge	**90**	**ft.**	**5**	**50**	**6-May**	**4500**	0.002043	9
3	Loop Rd	Bridge to East Road	2.35	mi.	5	50	6-May	117.5	1.8197	214
4	East Rd	North Road to Loop Road	3	mi.	10	210	9	630	1.3657	860
4a	East Rd	B10-100 bridge	**100**	**ft.**	**10**	**210**	**9**	**21000**	0.000704	15
5	North Rd	East Road to Loop Road	2	mi.	5	50	6-May	100	1.8197	182
						vpd			$/VMT-VFT	$ per day
		Road totals	9.4					950		1443
		Bridge totals	190					25500		24
										1467

Bridge removed

Road IDs, segment lengths, and level of service			Segment			Traffic	Traffic			
Sgmt#	Route	From/To	Length	Units	LOS#	volume	Band	VMT/VFT	UCT	TCT
1	Loop Rd	North Road to dead end	1.5	mi.	5	20	3	30	2.3693	71
2a	Loop Rd	B5-20 bridge	**0**	**ft.**	**5**	**0**	**3**	**0**	0.001978	0
2b	Loop Rd	B5-24 bridge	**0**	**ft.**	**5**	**0**	**3**	**0**	0.002043	0
3	Loop Rd	Bridge to East Road	1.35	mi.	5	20	3	27	2.3693	64
4	East Rd	North Road to Loop Road	3	mi.	10	240	9	720	1.3657	983
4a	East Rd	B10-100 bridge	**100**	**ft.**	**10**	**240**	**9**	**24000**	0.000704	17
5	North Rd	East Road to Loop Road	2	mi.	5	100	7	200	1.6957	339
						vpd			$/VMT-VFT	$ per day
		Road totals	7.85					977		1457
		Bridge totals	100					24000		17
										1474

Bridge remove / replace analys	Quantities			TCT		Difference	Percent
Summary	Roadway	Bridges	VMT	Daily	Annual	From Existi	of Existing
Existing situation	9.4	170	950	1464	534511.6	0	100.00%
Existing situation + bridge repl	9.4	190	950	1467	535340.8	829.2	100.20%
Bridge removed	7.85	100	977	1474	538153.8	3642.2	100.70%

Net extra annual TCT if bridge is closed	Net Diff	2813
Twenty year present worth of TCT savings		27596
Cost of increased length of replacement structure		31200
Savings to cost ratio :		0.884482

Curve realignment - evaluation of options

Items	Existing Alignment	Alternate #1	Alternate #2	Rate or unit cost	Units
Distance from A to B	2.407	2.344	2.184	NA	miles
Reduction from existing	0	-0.063	-0.223	NA	miles
Traffic volume	250	250	250	NA	vpd
VMT	219639	208141	178941	NA	VMT/year

Project quantities

Project length	0	0.568	0.909	$214,035	per mile
Old road to remove	0	0.341	1.132	$61,742	per mile
ROW added	0	5.51	8.815	NA	acres
ROW reverted	0	3.306	10.977	NA	acres
Net ROW change	0	2.204	-2.162	$1,800	per acre

Project costs

New road	$ -	$121,572	$194,558	Dollars	
Old road removal	$ -	$21,054	$69,892	Dollars	
ROW acquistion	$ -	$9,917	$15,866	Dollars	
Totals	**$ -**	**$152,543**	**$280,316**	**Dollars**	
Less reverted ROW	$ -	($2,975)	($9,879)	$900	per acre
Net cost	**$ -**	**$149,568**	**$270,437**	**Dollars**	

Operational changes on the 1.132 miles affected by Alternates 1 and

Average speed	30	35	43	NA	mph
Dwell time in project zone	0.037733333	0.032342857	0.026325581	$16.76	per hour
Time saved per trip	0	0.005390476	0.011407752	NA	hours
Excess time cost saved	**$ -**	**$8,244**	**$17,446**	**Dollars/year**	
Accident rate	3	2.8155	2.631	NA	er 1E6 VMT
Annual Accidents	0.65891625	0.62442375	0.53682375	$19,451	per acc.
Accident costs	12,816.58	12,145.67	10,441.76	Dollars/year	
Excess Acc. cost saved	**0**	**670.91**	**2,374.82**	**Dollars/year**	
VMT reduction	0	11498	40698		
VMT reduction savings	**$ -**	**$14,613**	**$51,727**	1.271	$ per VMT

Sum of all savings	**$ -**	**$23,528**	**$71,548**	**Dollars/year**
20Yr PW of savings	**-**	**230,811.26**	**701,883.81**	
Savings to Cost ratio	**NA**	**1.54**	**2.6**	

Design exception analysis -- should sharp hill crest be flattened or not

Items	Existing East road situation	Design Exception LOS-10	Standard LOS-10 design	Rate or unit cost	Units
East road					
Hill grading zone length	0	0.3	0.55	NA	miles
Centerline cut at crest	0	1	8	NA	feet
Traffic volume	250	250	250	NA	vpd
VMT in mile with hill	0.09125	0.09125	0.09125	NA	VMT
Quantity of grading required	0	10000	35500	$2	CY
Extra ROW needed	0	6	7.66	$2,400	Acres
Average speed of travel	37.5	45	50	NA	mph
Dwell time in the mile with the hill	0.026666667	0.022222222	0.02	$16.95	hours
Net time savings	0	0.004444444	0.006666667	$16.95	hours
Accident rate	3.602	2.6	2.297	NA	#/1E6-vmt
Annual accidents	0.3286825	0.23725	0.20960125	$19,451	Each
North road					
Hill grading zone length	0	0.05	0.2	NA	miles
Centerline cut at crest	0	1	8	NA	feet
Traffic volume	60	60	60	NA	vpd
VMT in .2 miles affecte by project	0.00438	0.00438	0.00438	NA	VMT
Quantity of grading required	0	250	5500	$2	CY
Extra ROW needed	0	0	2.01	$2,400	Acres
Average speed of travel	37.5	37.5	25	NA	mph
Dwell time in the mile with the hill	0.026666667	0.026666667	0.04	$16.49	hours
Net time savings	0	0	-0.013333333	$16.49	hours
Accident rate	3.602	3.602	3.854	NA	#/1E6-vmt
Annual accidents	0.0788838	0.0788838	0.0844026	$19,960	Each
Design exception zone totals					
Length of roadway involved	0	0.35	0.75	NA	miles
Total VMT	0.09563	0.09563	0.09563	NA	VMT

Project costs analysis (For items affected by proposed design exception)

	Item	D.E cost	LOS-10 cost	Difference
Earthwork	East Road	$20,000	$71,000	
	North Road	$500	$11,000	
	EW Sub-total	$20,500	$82,000	
	EW difference			$61,500
ROW	East Road	$14,400	$18,384	
	North Road	$0	$4,824	
	EW Sub-total	$14,400	$23,208	
	EW difference			$8,808
Net extra cost to build to full LOS-10 design guidelines vs. design exception				**$70,308**

TCT savings analysis (For items affected by proposed design exception)

	Item	D.E cost	LOS-10 cost	Difference
Fixed (Road network) costs	These costs will not be materially affected			
Vehicle costs	These costs will not be materially affected			
Human resource costs	East Road	$34,370.83	$30,933.75	
	North Road	$1,926.03	$2,889.05	
	EW Sub-total	$36,297	$33,823	
	EW difference			($2,474)
Accident costs	East Road	$4,614.75	$4,076.95	
	North Road	$1,574.52	$1,684.68	
	EW Sub-total	$6,189	$5,762	
	EW difference			($428)
Net annual TCT savings achieved by building to full LOS-10 standards vs. design exception				($2,902)
Twenty year PW of annual savings at I=8.00% apr				**($28,466)**
Marginal Savings to Cost ratio to go beyond the design exception profile				**0.4**

Chapter 9

SUMMARY AND CONCLUSIONS

9. Summary and conclusions

The objective of this research project was to define, implement, test, and evaluate a new concept for road based transportation decision support. The theory and methods devised and presented herein were given the name 'Total Cost of Transportation', or TCT, analysis.   The ideas thereof were used to create a physical and economic model of Iowa's county road network, which was then employed to test the ability of the concept to deal with system, segment, and project level issues. This chapter summarizes what was done, what was learned, and outlines potential future options.

9a. General

The Total Cost of Transportation concept and model answered most of the needs identified in Chapter 2. The concept appears to be viable, scalable, and capable of pooling knowledge from many sources into a small package: the model integrates data on the physical attributes of the transportation system, activity levels within it, the rate (speed) at which the activity occurs, the reasons for which trips are made, the frequency and severity of accidents, and links all such items to overall system economics.

9b. Findings in regard to TCT concept

9b-1 TCT concept validity

The TCT concept and theory proved able to handle a wide variety of issues and no fundamental flaws of principle or structure manifested themselves during any of the testing. Therefore, the author believes that the concept is valid.

As many professional readers will have no doubt observed, the concept is not entirely "new". Instead, it's a different approach to using engineering economics to evaluate alternatives.   The attributes that give it a unique character are:

a) that it views the road network as being just one sub-component of a much larger, more complex system composed of all things required for road based transportation to take place.
b) that it ignores and avoids trying to determine end user benefits, assuming that the interplay between perceived benefits and perceived costs is a market mechanism that establishes overall system size and activity levels.

c) that it performs its economic analysis strictly on the basis of absolute total economic cost of the overall system.

9b-2 Applicability

The issues investigated in this report suggest that TCT analysis is applicable to almost all design, planning, regulatory, finance, and public policy issues relating to road based transportation. Although this initial project dealt with county roads alone, both theory and model are capable of being applied to urban, state, and national systems with equal ease.

9b-3 Versatility

The basic concepts of TCT appear capable of linking economics, design guidelines, system adequacy, determination of upgrade needs, identification of individual road segments, and performance of specific project analysis. In addition, it seems able to be employed as a framework for discussion of regulatory, road finance, and vehicle technology issues with equal facility.

9c. Findings in regard to Database/Spreadsheet model

The initial database and spreadsheet model, of Iowa's county road system, was set up to permit evaluation of the theory and to determine if it could serve as a template for future TCT implementations. As discussed in the following subsections, it appears that the model was successful as a means of implementing the theory, produced valid results, and is capable of handling future refinements without needing redesign.

9c-1 Set up

A great deal of experimentation was required to find a workable format for both the database and spreadsheet models employed in this initial effort. But now that a basic structure has been worked out, it would not take long to set up new models of the same or other systems. Obtaining physical data was fairly easy -- but the collection, verification, and consolidation of cost information required extensive effort. Much of the cost data came in formats that weren't immediately useful, so considerable time had to be devoted to reprocessing it into a form that would integrate into the model.

9c-2 Validity

As noted several times in the text, the effort to collect and make cost data ready for use took so long that the numbers used for Chapter 7 and 8 were up eighteen months old when those chapters were developed. (February and March of 2002). So the findings about county roads drawn from the various analyses cannot be considered conclusive for 2002 conditions.

But if all physical and cost data were current, the results would become fully valid. Since the model does not perform any repeated calculations containing implied business rules or policies, it produces essentially unbiased results that derive directly from all inputs. Validity is enhanced by the model's ability to integrate all attributes of the system together at once, so that no aspect is overlooked.

Another factor that enhances validity is that TCT is essentially an open system: if a person wants to know how a certain result was arrived at, they will be able to trace all the way back to the original source data. It will be clear at all times where results came from.

The examination of order of magnitude confidence and range of probable error performed in Chapter 7 suggested that as long as source data was valid, results obtained from the TCT model would have a strong weight of authority.

9c-3 Ease of use

The ease of use was adequate for an initial effort and anyone familiar with databases and spreadsheets could easily reproduce the studies performed in this project. However, the system as so far implemented, would not be adequate as a tool for day-to-day use. A better front end for entering and defining the issue to be analyzed would be needed -- so that users could concentrate on getting results from the tool instead of focusing on how to operate it.

The largest obstacle to employing TCT methods would be obtaining and maintaining the underlying physical and cost information. If one wanted to be able to employ TCT on a "use-as-the-need-arises" basis, it would become necessary to keep the background data current. This would require a quantity of administrative overhead, in which someone would have to be designated and paid to make periodic updates.

9c-4 Versatility

The database/spreadsheet model proved to be very versatile. It proved fully scalable, could deal with a variety of issues, and could be used to frame all questions considered.

9c-5 Sensitivity

As used herein, sensitivity addresses the issue of whether or not changes in source data could produce disproportionately larger changes in model results. It does not appear that this is likely to be problem. First, the types of things that produce large swings from small changes are a) when one employs a model in which small numbers are divided into larger ones or b) where results are based partly or wholly on repetitively applied non-linear formulas. Neither case is present anywhere in the TCT model. In addition, the four major cost components: vehicles, human resources, roads, and accidents are each so large that large swings in their values is nearly impossible.

The greatest exposure to sensitivity in the current model actual derives from the traffic count data in the DOT base records. Because much of this information is estimated, it has been rounded to the nearest multiple of 5, 10, 20,or 50. Because of that, time interval type analyses can experience an effect where a large group of segments will collectively "jump" from one traffic band to another all at once, rather than "bubbling" upwards a few at a time. This would best be solved by more traffic counting or by artificially randomizing counts on certain classes of roads when making base record estimates.

Within this project, fatality costs were estimated to be around $200,000 per incident. Since that figure is much lower than what is normally use in highway decision making, a test was made to see how much accident costs would be raised if a conventional value were used. The results of this check indicated that average, per-accident rates would increase from about $19,500 to $32,000 if one used a figure of $1,000,000 per fatality. This would increase accident costs by roughly one half, making them more important in overall decision making. But, since accidents comprise only 3.5 percent of total costs now, they'd only increase to being 5.2 per cent of the whole – indicating that the model is not very sensitive to fatality cost level.

9c-6 Adaptability

The model appears capable of adapting to future refinements and new inputs without having to be restructured. Thus it may be able to serve as a platform that can combine and integrate principles and data from many other fields of study, such as highway capacity analysis, accident frequency / severity studies, trip purposes and costs, changes in speed limits, changes in vehicle capabilities, or improvements in traffic management.

9d. TCT utility in Road & Bridge network issues

This section summarizes what was learned about the ability of both theory and model to address the various technical issues that arise in the course of planning, building, and operating road networks.

9d-1 Project design and development

TCT proved capable of dealing with a variety of design issues:

9c-1.1 Design guides

The development of the Unit Cost of Transportation table enables one to define design guides based directly upon overall system economics. Such guides could even be dynamic, being updated automatically as underlying cost factors changed.

9c-1.2 Paving justification

TCT can serve as a supplemental tool for evaluating “should we pave this route or not?” situations. It probably would not make a good stand alone tool, though, because it wouldn’t directly address route continuity, economic development, or land use factors.

9c-1.3 Design exceptions

As demonstrated in Chapter 8, TCT methods can be used to perform design exception analysis and would integrate more factors into the decision than just accident statistics – and include consideration of the time value of money into the process.

9c-1.4 Evaluation of alternates

It appears feasible to use TCT to evaluate a variety of situations: whether or not to build new, whether or not to close old, to what degree to improve, or finding an optimal balance between level of service and cost of upgrade.

9d-2 Road system evaluation

TCT proved capable of being applied to many different aspects of system evaluation and adequacy analysis.

9d-2.1 Evaluation of service levels

Via the Service-Superior, Service Adequate, Upgrade Justified, and Upgrade urgent classifications defined in Chapter 7, it becomes possible to assess service level adequacy on both a system and segment level basis.

9d-2.2 Determination of capital improvement needs

The concept and model ably assisted in identifying, prioritizing, and quantifying capital improvement needs. Unlike most other methods, TCT would even advise when capital improvements *should not* be made.

9d-2.3 Revenue requirements

Due to the integration between system economics and the physical model, TCT is able to determine and declare what amount of revenue is required to operate and maintain any system configuration: existing, optimal, or adequate. The resulting figure is an absolute value that indicates what is required to maintain the system in steady state condition. Capital improvement needs are determined independently of operation and maintenance needs and identify what investment level is needed to minimize total system cost.

Taken together, the O&M and Capital needs costs constitute an objective, economics based declaration of what should be spent on a road network to assure that the total system can function at a least possible cost. This approach to revenue need determination is absolute. It does not attempt to use proportional ratios to divide available revenue between systems or jurisdictions. It simply declares what level of funding is required to keep total costs minimized.

9d-2.4 System behavior over time

Via the application of annual growth factors, the system can model traffic growth as shifts of miles between traffic bands within each LOS row. Improvements can be modeled as LOS shifts within traffic bands. New roads can be added in as new miles, with traffic levels on affected neighbor segments adjusted as needed. Road closures can be modeled as deleted miles and transfers of jurisdiction can be modeled as shifts of miles from one agency to another.

9d-2.5 Analysis of shifting system miles from State to Counties

TCT could be used to evaluate the proposition that counties should take over some roads now managed by the State DOT. The key issue, as TCT would frame it, would be whether the collective State/County system's Total Cost of Transportation could be reduced by shifting certain routes to lower cost county maintenance without greatly impairing travel time and accident cost situations. If such a jurisdictional shift were deemed advisable, TCT could help determine what amount of operation & maintenance and capital improvement resources that should be shifted to the counties along with the roads. Under ideal circumstances, such a shift would leave the DOT with more funds to spend on minimizing the cost of travel on the remaining state routes.

9d-3 Exploration of service strategies

TCT methods can probably assist with evaluating service and operation strategies as well as system size and design levels. The following sections briefly outline how this might be done.

9d-3.1 Comparison of alternate methods

If one wanted make system operation decisions, TCT could be used to frame the issues for analysis. For example, it could be applied to the question: "Should we perform 24 hour per day snow removal on any of our routes?" To answer, one would compare the extra costs of providing that level of operational service to potential gains in average speed of operation, reduction in use of longer alternate routes, and reductions in accidents. If the net savings exceeded the costs, providing the extra service would be justified. But if the savings to cost ratio was less than 1.2, one would probably conclude that lower service levels were adequate.

9d-3.2 Determination of system condition goals

A common feature of system maintenance tools, such as pavement management systems, is that they can help identify a program of maintenance and repair for maintaining the roads at a specified overall condition level. TCT could assist by facilitating a determination of what the target conditional level should be. This would require dividing LOS/T-band mileages into condition classes and then computing per-VMT costs for each class. Presumably one would find that the Unit cost of transportation would be minimized in one of the classes – thereby identifying an optimal condition level. As with levels of service, it's also likely that there would be a range of adequate conditions as well as superior and repairs-justified levels.

9d-3.3 Deciding optimum traffic densities

Although congestion is seldom a problem for counties, it often is an issue on state highways and city streets. Since TCT associates a least cost LOS with each traffic band, the reverse process could indicate the optimal or maximum traffic level that could be accepted on a road before total costs would begin to increase or before an upgrade would become warranted.

9d-3.4 Accident reduction options

The preparatory work on accident data indicated that the primary effect of design level is on accident frequency, with severity and cost per accident being roughly uniform for all county road types. And the total cost components breakdown showed that accident costs comprise only about 3.5% of system TCT. This suggests that road agencies can do the most good by eliminating spot hazards and by upgrading roads to higher service levels. But, overall, road agencies cannot achieve massive reductions of accident costs without grossly overbuilding their networks. Accident reduction will also require continued safety improvements to motor vehicles and perhaps regulatory changes to improve the average competency level of all drivers.

9d-3.5 Impacts of closing roads and/or bridges

As noted in Chapter 8, when roads or bridges are closed, the pattern of traffic flows is forced to rearrange to fit the new situation. Typically, this type of traffic shifting results in an overall increase in total vehicle miles of travel, and travel time. TCT can assist in evaluating whether such cost increases offset the savings realized from discontinuing maintenance and repair of the road or bridge.

9e. Applicability to public policy issues

Although this research project did not specifically study the applicability of TCT methods to framing and deciding public policy issues, the author believes that it could be done. The following sections provide brief descriptions of how such analyses might be set up and performed.

9e-1 Transportation system size & service levels

At the top level of any debate about the future of transportation, almost all discussion can be distilled into three questions:

1. How big, (in route miles), should the system be?
2. How high a level of service should be provided on each mile?
3. Who should bear the cost?

TCT seems capable of supplying guidance on question number two directly from the Unit Cost of Transportation table. The size of system issue would be harder to address, but could be done by posing and answering three additional questions:

1. How would existing travel distance, travel time, and accident levels be redistributed by the size change?
2. By what percentage would overall travel, (number of trips per day), increase or decrease?
3. To what degree would society's non-transportation costs be increased or decreased?

TCT would not be able to answer question No. 3 but might be of assistance in helping evaluate the various schemes that might be put forth.

9e-2 Road and bridge network funding / pricing

Since road networks are maintained with taxes, a dynamic tension always exists between the public's appetite for good roads and their resistance to having to pay the supporting levies. TCT methods could enable transportation professionals and elected officials to frame the issues in ways that would help the public see that the choice is between lower taxes or lower total costs. One could either define a range of system size, service, and condition levels, then ask, (in some fashion), the people to choose which one they want to have – then report what tax levels are required to achieve that target. Or citizens could be asked to specify what tax level they are willing to impose on themselves, with TCT methods then report what system and total cost could be supported thereon.

9e-3 Operating regulations

Restrictions imposed by law on how roads can be used affect the costs of using them. Things like allowing or prohibiting parking, embargoing roads during certain periods of the year, controlling haul routes, or specifying a minimum number of occupants for use of a special freeway lane are all examples of this. Properly framed, TCT methods would enable objective reviews of such controls – both of effectiveness and for deciding when to use them.

9e-4 Vehicle regulations

The size, weight, fuel economy, and operational safety of vehicles are very important to the cost of the transportation system, since vehicle related costs constitute roughly one half of the total. Thus, changes in the laws that control vehicle design can materially change system economics. Some of the economic tradeoffs that could be analyzed with TCT methods include:

1. Permitting heavier trucks will reduce the total number of trips required to haul freight from one place to another, creating a savings in travel distance and time costs. On the other hand, increased loads cause existing pavements to wear out faster and require that heavier slabs be used to replace them – increasing fixed costs.
2. Allowing triple-trailer semis would enable a reduction in total vehicle miles of travel and cut the number of drivers required – both reducing costs. But they might also make passing harder – slowing average speeds of all vehicles – and increase accident rates or costs.
3. Mandating the inclusion of passenger protective systems, such as air-bags, boosts vehicle based costs while helping cut injury expenses.

9e-5 Driver regulations

Unlike most other transportation operator situations, where only the most competent individuals are entrusted with operating vehicles, road based transportation excludes only the least competent. Imposing more restrictive licensure requirements would greatly enhance safety, but would force society to fulfill its overall transportation needs with more travel by fewer drivers or by finding ways to accomplish personal goals with less travel. Liberalizing licensure would have the opposite effect. Each case features its own economic gains and losses. Requiring adult drivers to undergo periodic training in how to deal with driving emergencies is another example – where one would need to compare the cost of the training vs. any resulting accident cost reduction.

9e-6 Selection of speed limits

In economic cost terms, speed limits represent a balance between minimizing travel time costs vs. the opposing goal of minimizing accident costs. Also, higher speeds tend to reduce the perceived price of travel, which induces an increase in total travel. Lower speed limits, of course, have the reverse effect.

9f. Analysis of system dynamics

The TCT concept and model may also be applied to examining situations where there are dynamic relationships.

9f-1 Impact of increasing RUTF taxes

Increasing RUTF taxes will increase the perceived price of transportation and, mostly likely, cause a small decrease in overall activity. But the increased funds will permit making improvements that lower distance and time costs, tending to reduce the price and increase activity. TCT may be used as both a framework for studying this type of interaction and/or as a tool for predicting the impact of such tax changes.

9f-2 Road improvement induced traffic growth

Another perspective on the balance between revenue vs. financial needs would be to ask, in TCT format, how much total travel and RUTF revenue will grow if the road network is improved to a certain level. A key question would be whether or not the revenue increase would be adequate to fund the cost of making the improvements.

9f-3 Interaction of transportation with land use

An area that needs more study, yet probably cannot be ever fully reduced to straightforward analysis, is the relationship between transportation and land use. Since expansion of the transportation network decreases the cost of accessing and using land, it promotes development. Development, in turn, creates traffic increases that demand expansion and improvement of the roads. Each one influences the other. Yet the relationship has limits: building new roads in an area where development potential is low will not yield much growth. And sometimes development springs up for reasons other than transportation availability. TCT methods could be employed to study the land use – road improvement interaction, both in general and site specific situations.

9g. Areas for improving TCT model

While the database and spreadsheet model developed for this project proved relatively successful at modeling most physical and economic attributes of the road based transportation system, there were some factors that weren't fully addressed. The following sections identify them, discusses their potential significance, and outlines how they might become fully accounted for in the future.

9g-1 Road system elements

9g-1.1 Profile and alignment

The assignment of road segments into Level-of-Service, LOS, categories was done on the basis of surface type, number of lanes, paved width and total shoulder-to-shoulder width. This approach included an implicit assumption that all roads having a certain surface, lane number, pavement, and shoulder characteristics also have similar horizontal and vertical geometries. That is generally, but not universally valid, so it would be appropriate to develop criteria for up-rating or down-rating a segment's level of service if its profile and alignment were different from the assumed mean.

9g-1.2 Clear zone

Clear zone widths have a material impact on accident rates and costs but the DOT base records did not carry any data on them. As with Profile and Alignment, there may be a need to adjust LOS assignments when clear zones are wider or narrower than average.

9g-1.3 Regional variations in road costs

The cost model used in this project did not account for regional differences in material and labor costs, even though decisions for a specific county will be most reliable when based specifically on their local cost picture. If additional accuracy is necessary, regional cost multipliers for all cost elements, not just roads, would be needed. The interaction can be complex: in a locale with depressed per capita income, reduced driver travel time costs would be offset by the fact that labor costs in producing rock for gravel roads would also be less. But one could also find that another lower income level county would have to haul in expensive rock from a significant distance – which would result in a substantially different mix of TCT cost components.

9g-1.4 Mobility impacts of weight restricted bridges

Evaluation of the cost of having load posted bridges is made difficult by the fact that existing traffic counts show traffic flow patterns as they are with the restrictions in place – not how it would be flowing if the bridges were all of full capacity.

9g-1.4 Modeling of road & bridge condition status

As noted earlier, this project presumed that, overall, one could say that the road network has, in the recent past, been sufficiently financed to be maintained at a stable condition level. In cases where that is not true, one would need to make both the physical and UCT models three dimensional – perhaps setting up 5 or 10 condition range levels into which the miles of each LOS/Traffic-band combination could be further divided.

9g-2 Cost factors not fully addressed or developed

Several cost factors were not fully developed in this project, since they were not closely tied to the cost of the county road system. This section identifies them and addresses how they could be dealt with.

9g-2.1 Parking facilities

Destination parking facilities, whether at shopping centers, schools, or offices, represent a cost of transportation that usually is not specifically charged as a transportation related expense. At malls, the parking costs are reflected in the price paid for merchandise while a business usually absorbs the cost of employee parking as part of its building and grounds expense budget. So customers and workers seldom perceive that there is any cost associated with parking. Nonetheless, parking facilities do represent major capital and operational costs of the system and should be included in the UCT table. The question is where and how to allocate it. Should it be treated exclusively as a cost associated with vehicles – and thereby included TCT as a travel distance based cost, or should it be assigned, partially or fully, to abutting roads and treated as a fixed cost? In this trial project, the author elected to assign one half the estimated cost of destination parking to vehicles and half to adjacent streets. This was an arbitrary choice that sufficed for the county road system. But this issue needs more study.

9g-2.2 Economic and business costs

This entire cost category needs more study and better data. However, since it seems to form such a small percentage of total costs, the need probably isn't urgent.

9g-2.3 Social & environmental costs

Social and environmental costs were not a significant factor in county road economics but definitely could be in urban and high traffic situations.

9g-2.4 Determination of cost offsets

As with economic and business costs, this is an area that needs more study and more data. But it's such a small part of the total cost picture that the need isn't urgent.

9g-3 Additional questions

Some additional items that were identified during the course of the project but not fully determined were:

9g-3.1 Variation in vehicle costs with traffic level

It seems probable that the per-mile cost to operate a vehicle on a particular level of service should vary with traffic level. Costs should be least when a vehicle "has the road to themselves" greatest when it is stuck in congested, stop-and-go traffic. But this issue has not been widely studied and no reliable information was available. So the author chose to figure vehicle costs as if they were the same at all traffic levels. In the future, an effort should be made to determine if costs do vary with traffic level or not and, if so, how much.

9g-3.2 Variation of accident rates with LOS and traffic

The accident data available from ALAS was not capable of being divided into specific level-of-service and traffic band categories. The author was able to overcome the first problem and produce fairly accurate accident rate and cost information on a per-LOS basis. But, as with vehicle costs, he was not able to determine if there is a variation of accident frequencies and severity with traffic level. In the future, an effort should be made to determine if costs do vary with traffic level or not and, if so, how much.

9g-3.3 Role of in-vehicle communications

Cellular telephone technology is having a profound impact on road based transportation. Prior to such phones becoming available, paid travel time fully qualified as a cost of transportation because the driver was unable to perform any other tasks. Now, drivers can continue conducting business while in motion, which means that cell phones tend to reduce the economic cost of travel time. And they permit closer coordination between traveler and destination, resulting in both decreased miles and time of travel. On the other hand, mobile telephone technology is not free and, at least partially, constitutes a new cost of transportation. This project did not attempt to unravel this complicated new issue, but it must eventually be examined.

9g-4 Data quality and collection

As noted in Chapter 7, road data and cost information was easiest to obtain, followed by accidents, vehicles, and human resources – in order of increasing difficulty. Business, economic, social, environmental, and offset costs were hardest to find and document.

9g-4.1 Vehicle data

Vehicle data could be better if the tracking of VMTs by vehicle type better matched the categories used in motor vehicle licensure documentation.

9g-4.2 Human resource information

Determining the economic cost of paid time consumed while operating or riding in a vehicle is an area open to improvement. Accurate licensed driver information from the DOT provides a good starting point but trip purposes, percent of trips taken while "on duty', and the pay rates that apply to travel time hours all need more research.

9g-4.3 Traffic counts

Traffic counts are critical to the successful use of the TCT method. Actual counts have been performed on most paved routes but the AADT figures available for most gravel and earth roads are estimated. Some additional work should be done to improve the accuracy of such estimates.

9g-4.4 Speed of travel

An area where additional research is needed is in determining the average speed of travel on roads associated with the various level-of-service categories. The average speed of travel is not the same thing as the speed limit, or even the average speed clocked by radar at a particular point along a road. It is a measure of how much time is required, by all vehicle types, under all conditions, to get from all their points of origin to their destinations. This is best computed by dividing total travel on a route, in VMTs, by the total hours spent generating those VMTs. Since measuring total hours isn't possible, the approach outlined below might be a good substitute:

1. Record spot speeds at various locations and develop an average running speed.
2. Drive a representative section of roadway a number of times at the average running speed and record total time and miles. Trip time should be from origin to destination including all stops, turns, passing maneuvers, and other typical driving actions.
3. Compute the average speed of travel by dividing total distance by total time.

This approach would give a good indication of travel speed in good weather. One would then need to reduce it to reflect the percent of time throughout a year that conditions prevent vehicles from operating a normal speeds.

9h. Potential extensions of the method

There isn't any reason why TCT couldn't be applied to other modes of transportation. One could employ TCT methods to study inter-modal cargo transport issues – evaluating the total costs of using the two modes in combination vs. the costs of using them separately. Or trucking and highway officials could use TCT as a framework for discussing how changes in vehicle designs coupled with matching improvements to the road network might be able to reduce total costs of transport.

9i Review of original questions

Having started this project on the basis of a series of questions, having identified concept and technique improvements needed to address those questions, then developing and testing a theory to meet those needs, it seem appropriate – at the end of this report – to reprise the questions and explore how TCT would lead us to answer them. Thus, eleven of the original key issues are listed below, along with a brief analysis.

9i-1 Can one find an "optimal" match between traffic and LOS?

Yes : it appears that TCT can recommend a Level-of-Service that will afford the least total cost of operation in any traffic band.

9i-2 Should road funds be allocated by VMT rations?

No : the objective of operating a road system is to minimize the total economic cost of transportation. This calls for spending money in a way that provides each route with a level of service on which traffic can operate at least cost.

9i-3 Can design exception analysis be improved on?

Yes : Using TCT methods, one could integrate consideration of all relevant factors into the design exception decision – not just accidents.

9i-4 Do regional planning processes improve results?

Unknown : TCT has turned out to be a tool that could be used for regional analysis as well as statewide or local. But it isn't really set up to evaluate the merits of the regional planning process itself. The question would be whether or not such planning has helped lower the total cost of transportation in some way.

9i-5 Can a minimum standard rural road standard be found?

No: TCT suggests that there is an optimal service level for each level of traffic, not that there is an absolute minimum level of service that ought to be provided.

9i-6 How should RUTF funds be allocated between counties?

RUTF funds should be divided first to help finance the preservation of the existing system and second to finance warranted improvements.

9i-7 Does the popular notion of the self-serving highway lobby mesh with reality?

No: The players in the road network arena: agencies, engineers, and contractors, are just engaged in a never ending effort to keep costs minimized as total system activity grows.

Yes: businesses that build roads or depend heavily on them benefit from road improvement efforts and are thus inclined to promote them.

9i-8 Have counties been guilty of paving roads without adequate justification?

Yes: every county has paved some miles which didn't really merit upgrading.

No: TCT analysis indicates that only 3.4% of county roads significantly exceed the needs of the traffic they carry – and that percentage declines as traffic counts grow.

9i-9 Can TCT methods help determine sufficiency ratings or replace them?

Yes: they can help.

No: sufficiency ratings will always have a role.

9i-10 Can TCT methods help with setting up and operating asset management systems?

Yes: TCT could be used to help determine what condition level a road network ought to be maintained at – for the purpose of achieving minimum total cost. So it could assist in picking the targets for the management system to aim at.

9i-11 How can the transfer of jurisdiction impasse be resolved?

TCT can't answer how this problem should be solved. But it could play a role in helping people evaluate alternatives. The ultimate goal of both the DOT and the counties should be to work out an exchange of miles and funding that would help minimize the total cost of transportation of their two systems combined.

9j Final conclusions

Final conclusions regarding TCT and the model are stated below:

TCT theory and concepts

The theory and concepts for the Total Cost of Transportation method appear sound and workable.

TCT database/spreadsheet model

The combination database and spreadsheet model developed to test the TCT concept proved flexible, stable, scalable, and able to deal with issues on a design-guide, statewide, county-by-county, segment-by-segment, and project-by-project basis.

Author's personal note

The original thinking that led to the development of this project occurred in 1994. It took a couple of years to get to the point of being able to seek Iowa Highway Research Board authorization and funding to proceed. Subsequently, job changes, competition from other responsibilities, and the need for time to reason things out made it hard to prosecute the work and move this project forward. But, whenever possible, an effort was made to progress by at least one more step. Although it has taken six years, the accumulation of effort finally paid off and the project is now completed.

The author deeply appreciates the patience and support of DOT's Research Office Staff, who offered periodic advice and time extensions, and the Mills County Board of Supervisors, who underwrote the project when originally presented to the Research Board.

Future options

- TCT's development helped identify the need for more knowledge about travel speeds, accidents, trip purposes and time costs, vehicle costs, and many other factors. Research into such areas is recommended.

- TCT did not address the issue of cost variation with road condition in this effort but that is something that should be done.

- TCT could be made available for use as a day to day tool, but would require a simplified interface and maintenance of a central cost database.

- TCT concepts can be used to frame road and transportation issues for discussion, even if not formally employed in the analysis.

- System, county, and segment level analysis results would be greatly enhanced if they were linked with and able to be displayed in a GIS system.